March 19, 1963 H. S. SOMMERS, JR 3,082,415

METHOD AND APPARATUS OF TARGET ACQUISITION

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FIG. 1B

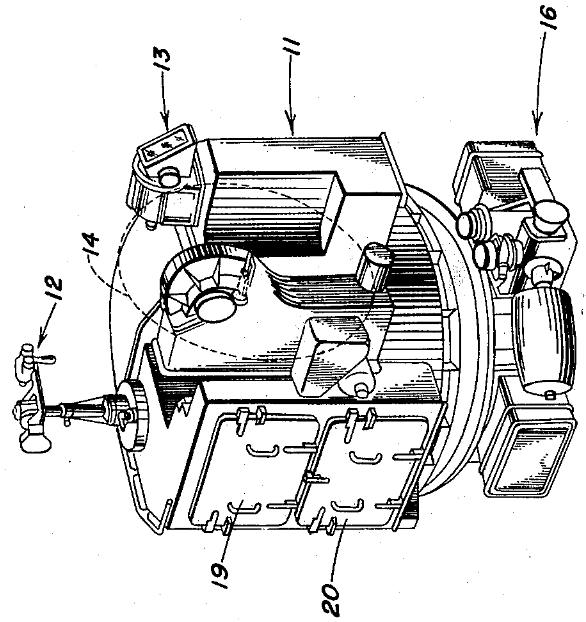
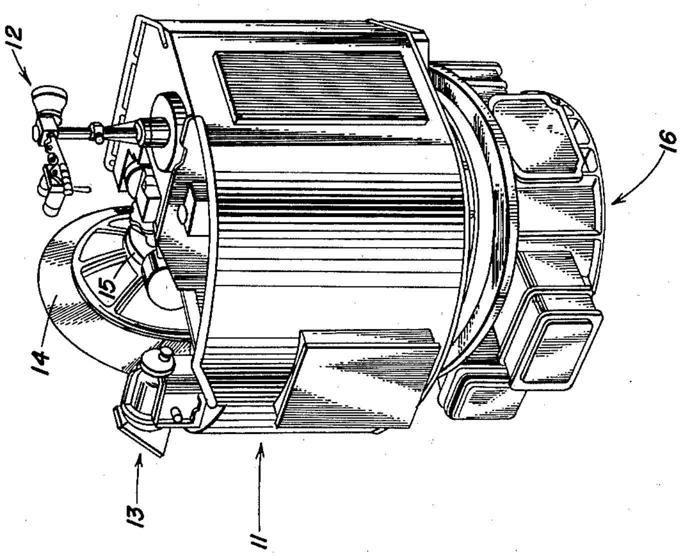


FIG. 1A



INVENTOR
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BY G. D. O'Brien
ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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FIG. 2

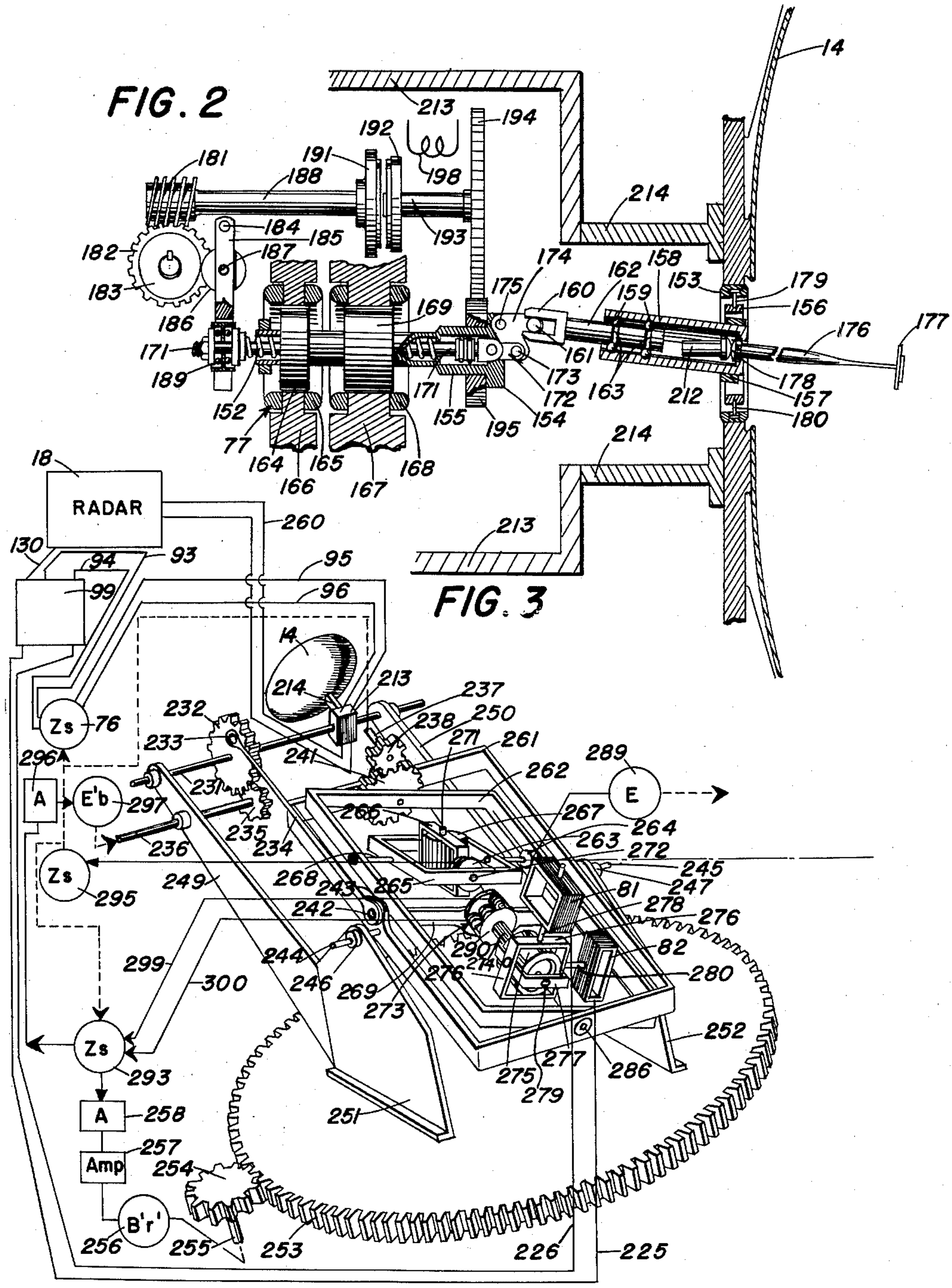


FIG. 3

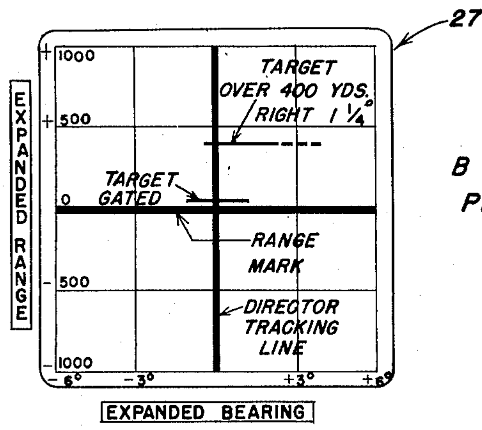
INVENTOR

HENRY S. SOMMERS Jr.

BY G. D. O'Brien

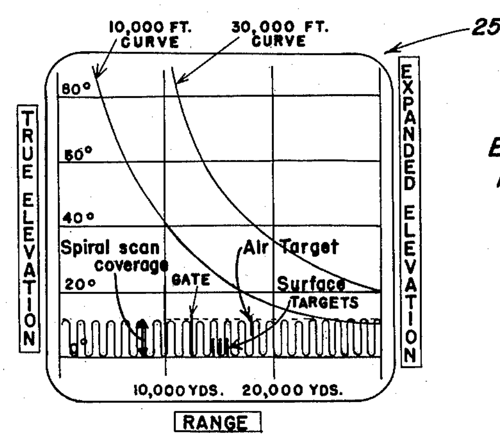
ATTORNEY

FIG. 4A



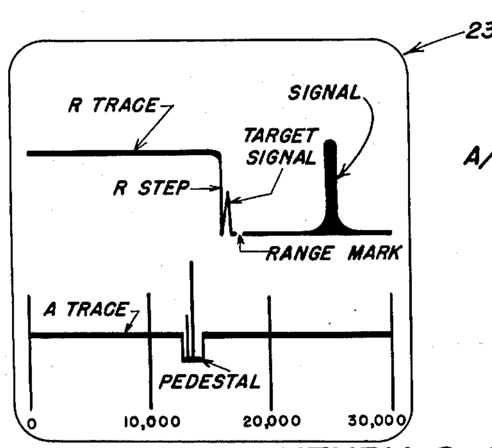
B INDICATOR PRESENTATION

FIG. 4B



E INDICATOR PRESENTATION

FIG. 4C



A/R INDICATOR PRESENTATION

INVENTOR
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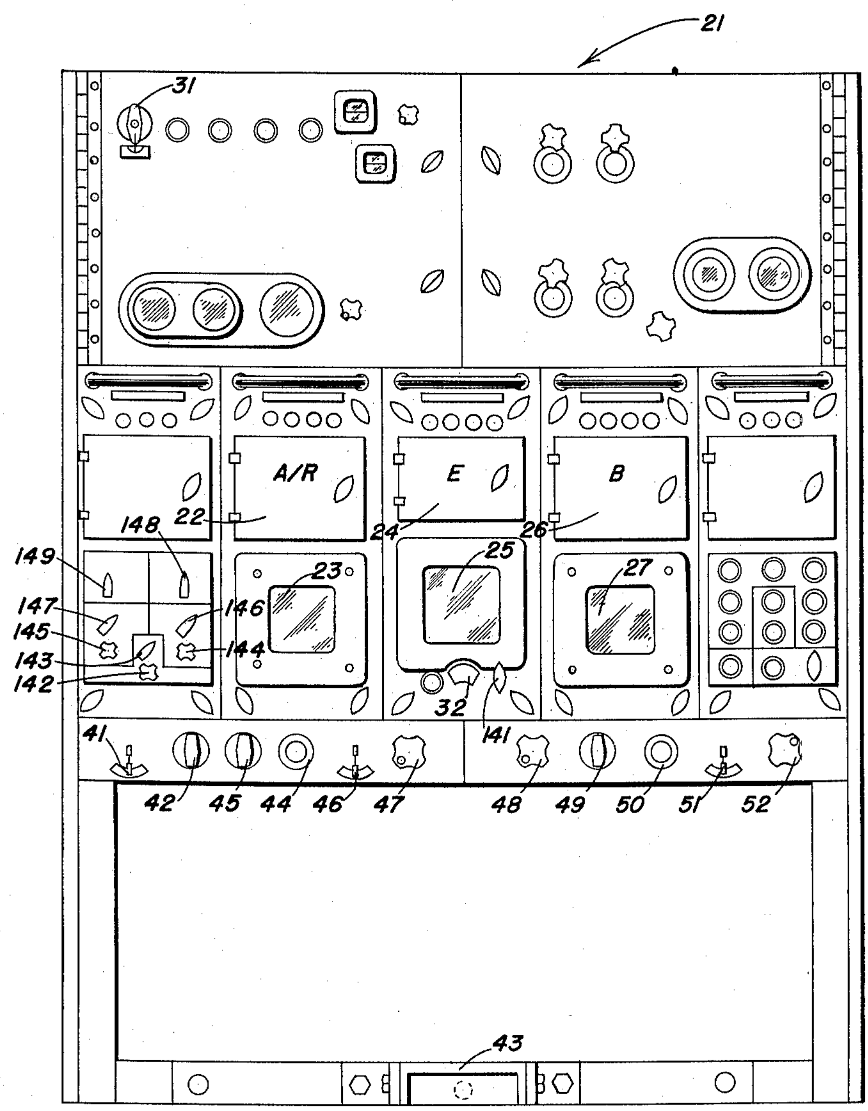
BY G. D. O'Brien
ATTORNEY

FIG. 5



CONSOLE

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

FIG. 6A

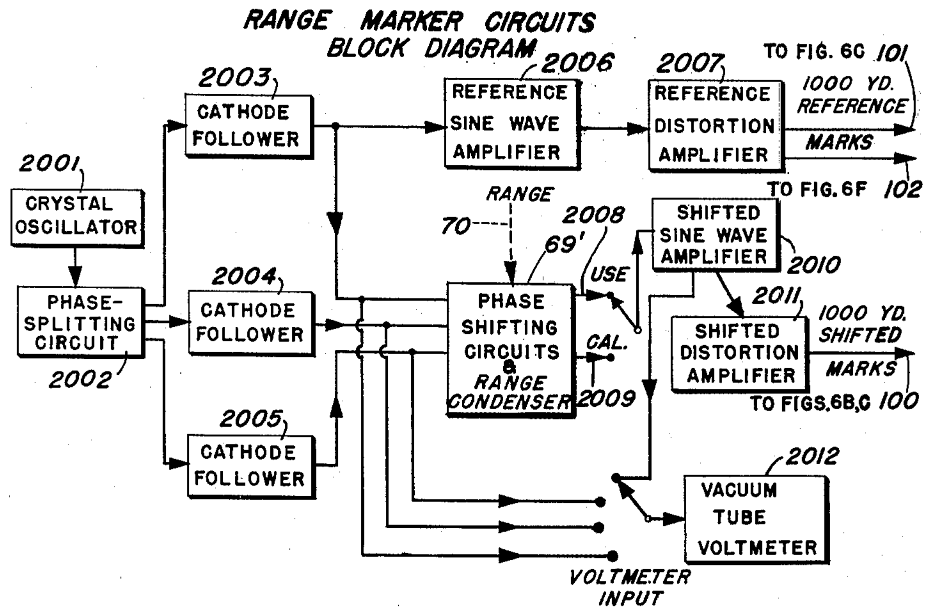
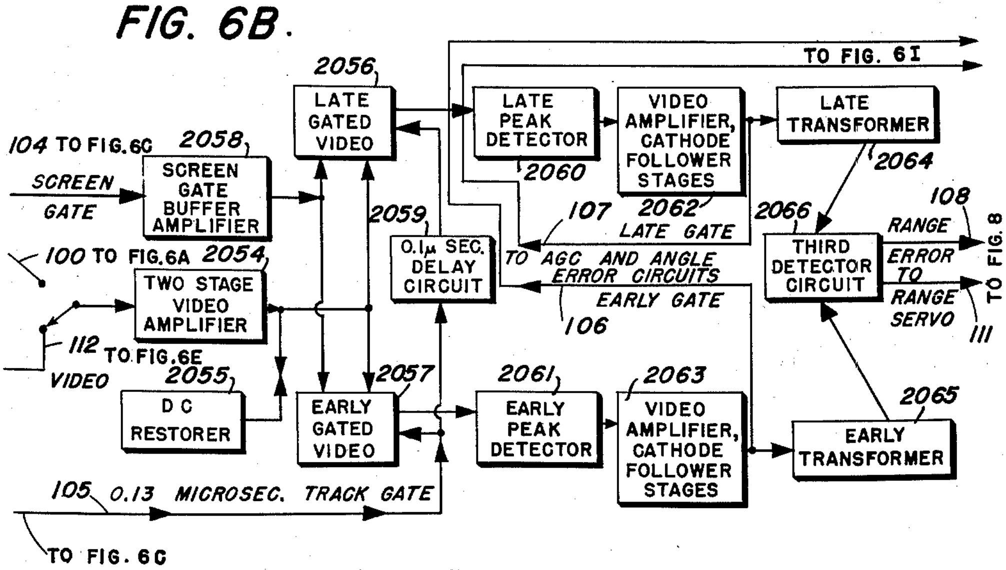


FIG. 6B.



RANGE ERROR DETECTOR
BLOCK DIAGRAM

INVENTOR
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BY [signature]
ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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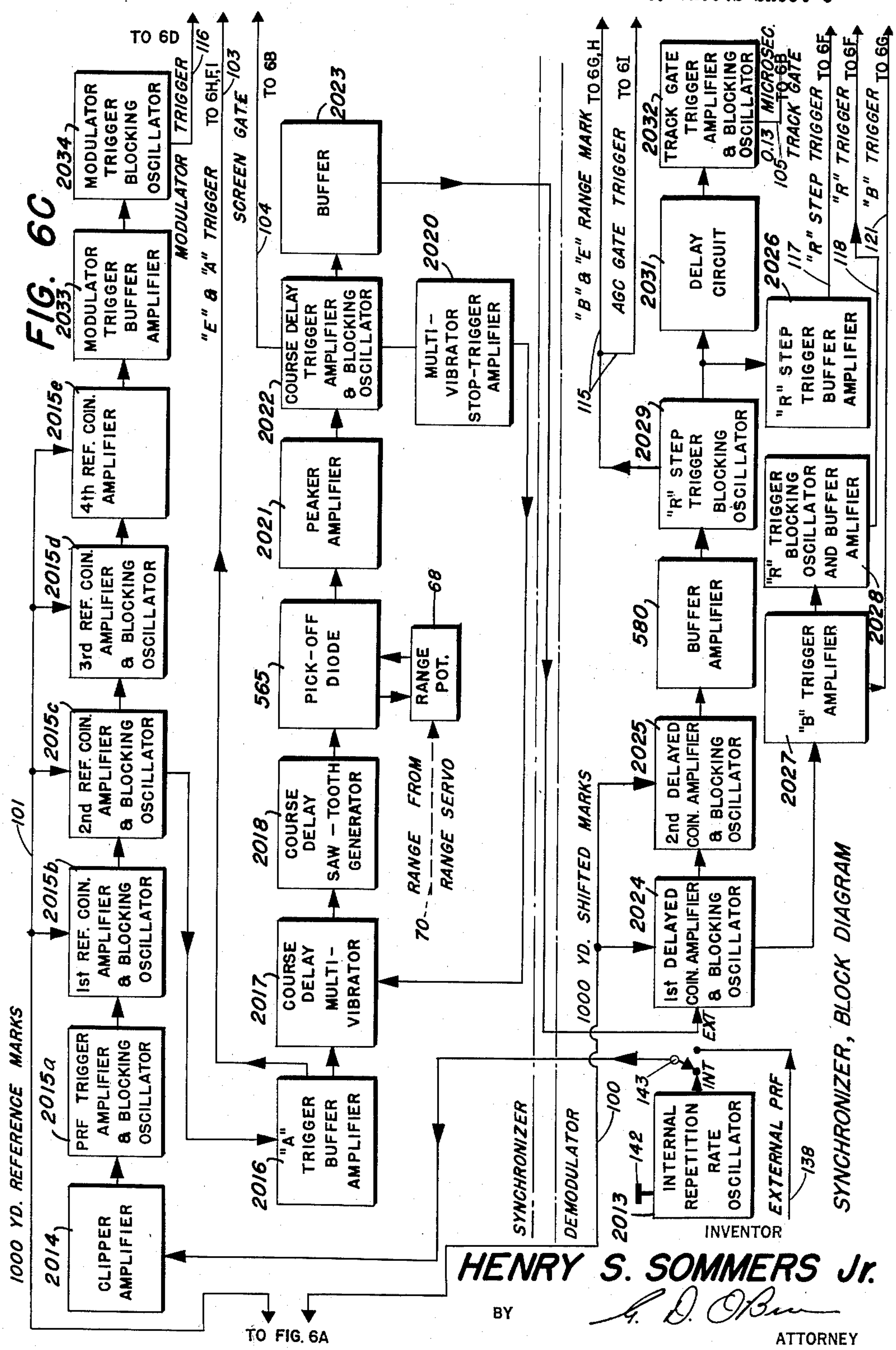
FIG. 6C



INVENTOR

HENRY S. SOMMERS Jr.

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ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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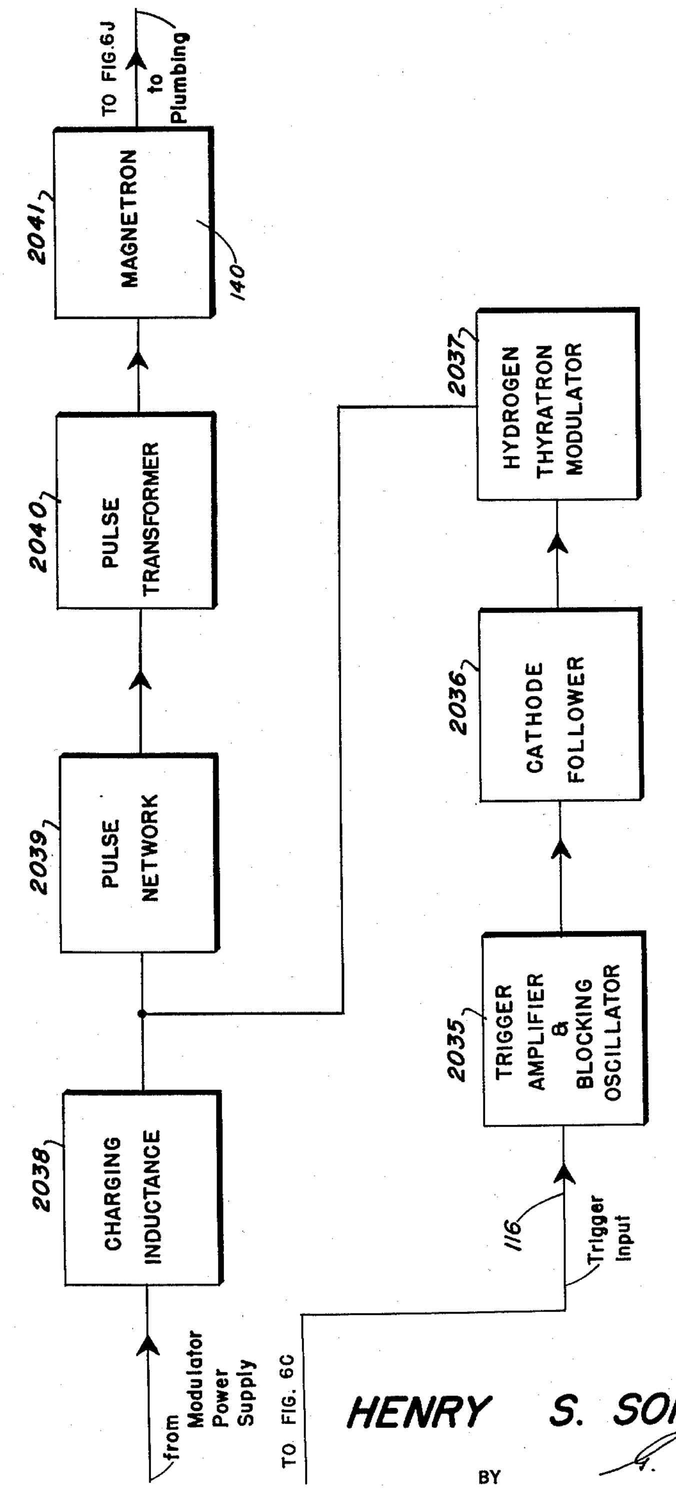
FIG. 6D



MODULATOR AND TRANSMITTER

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
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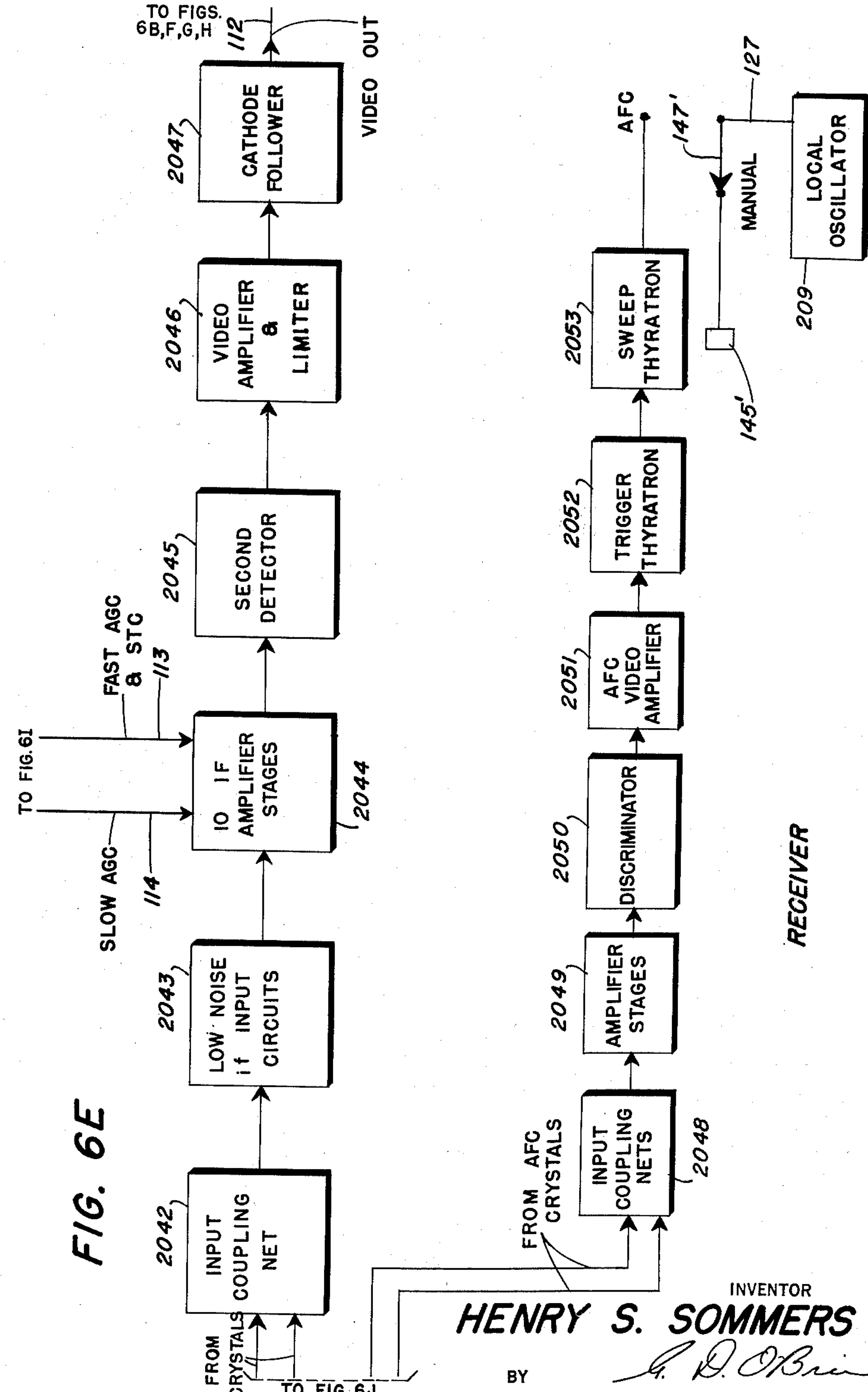
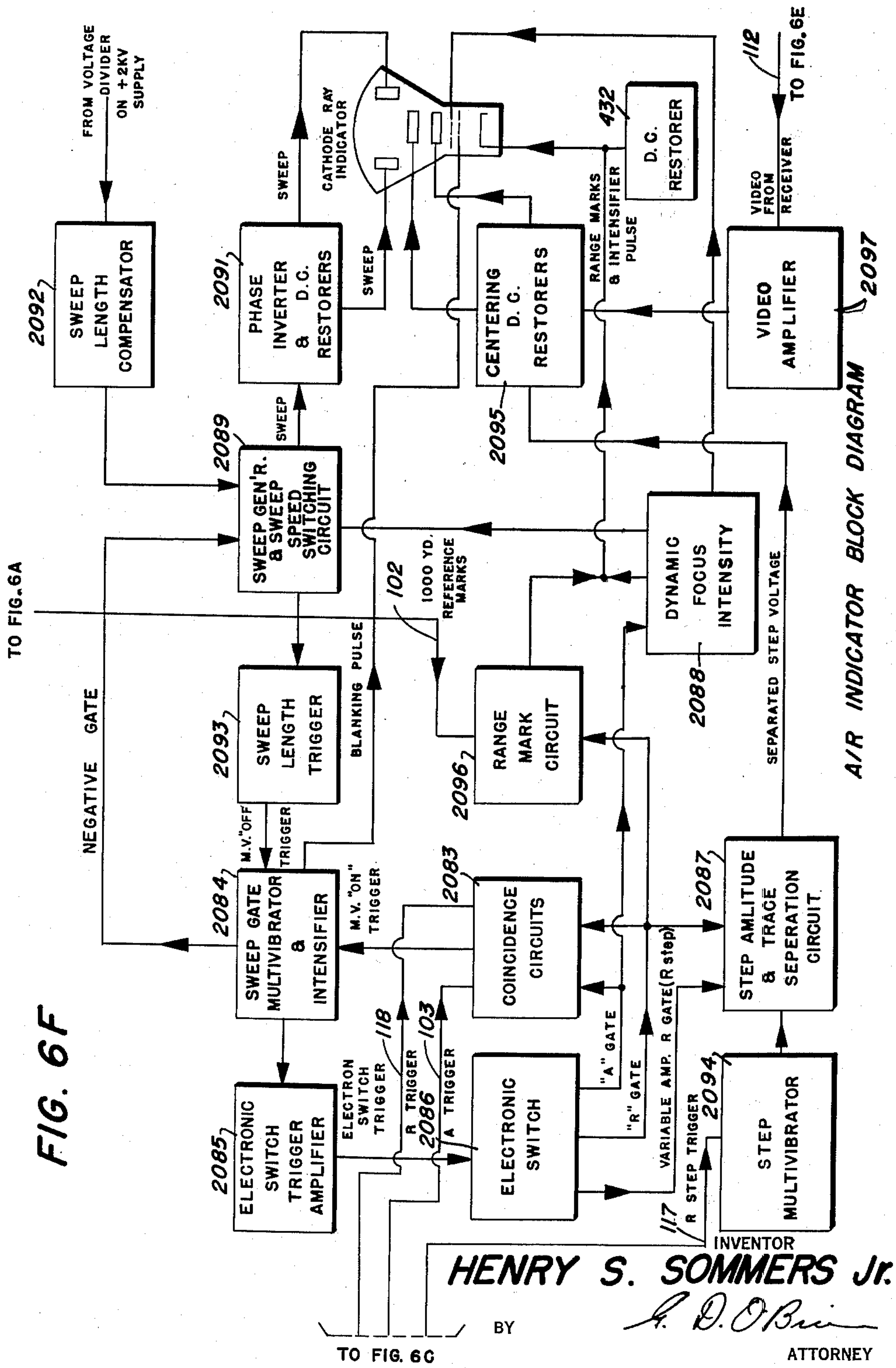
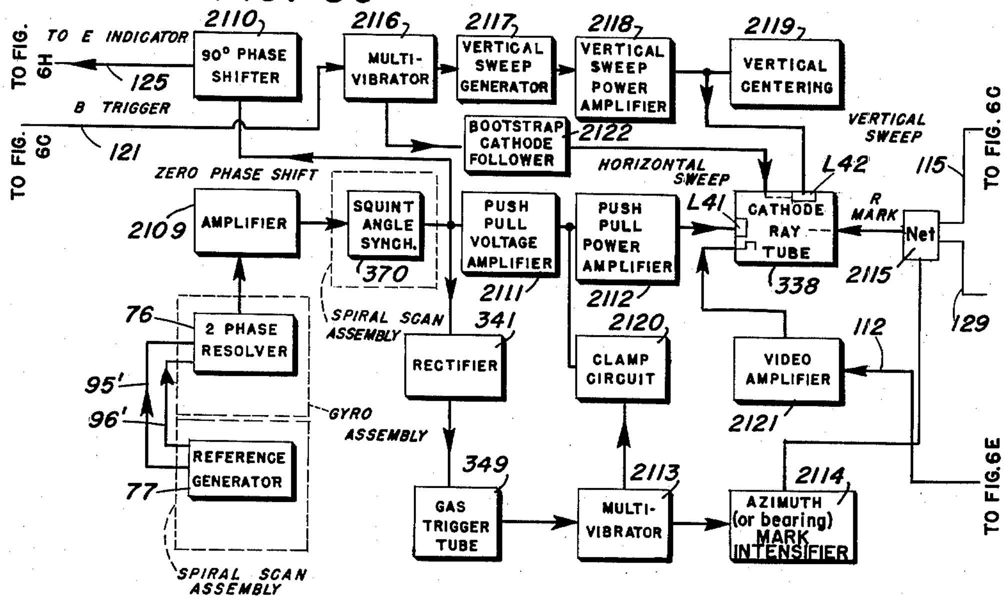


INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY



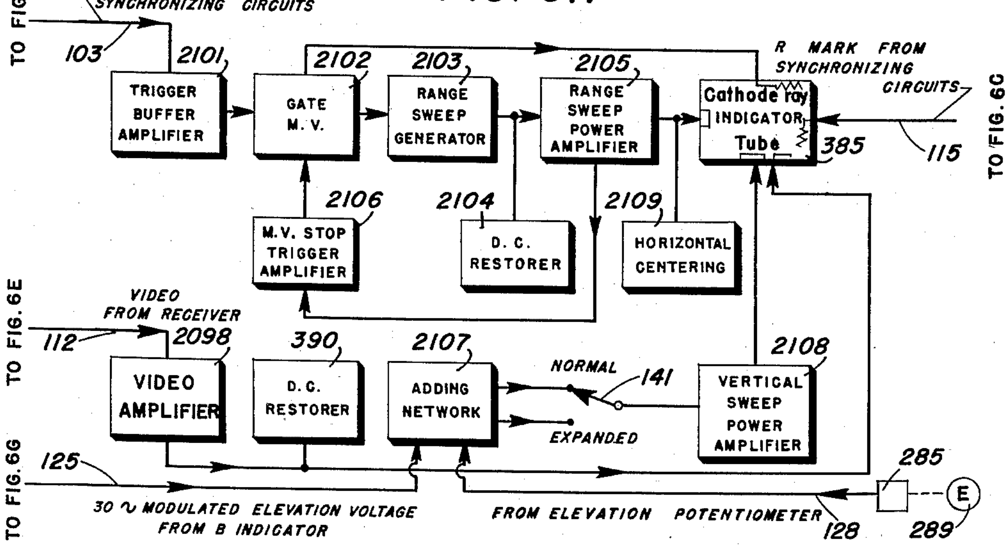
INVENTOR
HENRY S. SOMMERS Jr.
BY
G. D. O'Brien
ATTORNEY

FIG. 6G



B INDICATOR BLOCK DIAGRAM

FIG. 6H



E INDICATOR BLOCK DIAGRAM

INVENTOR
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BY G. D. O'Brien
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March 19, 1963 H. S. SOMMERS, JR 3,082,415

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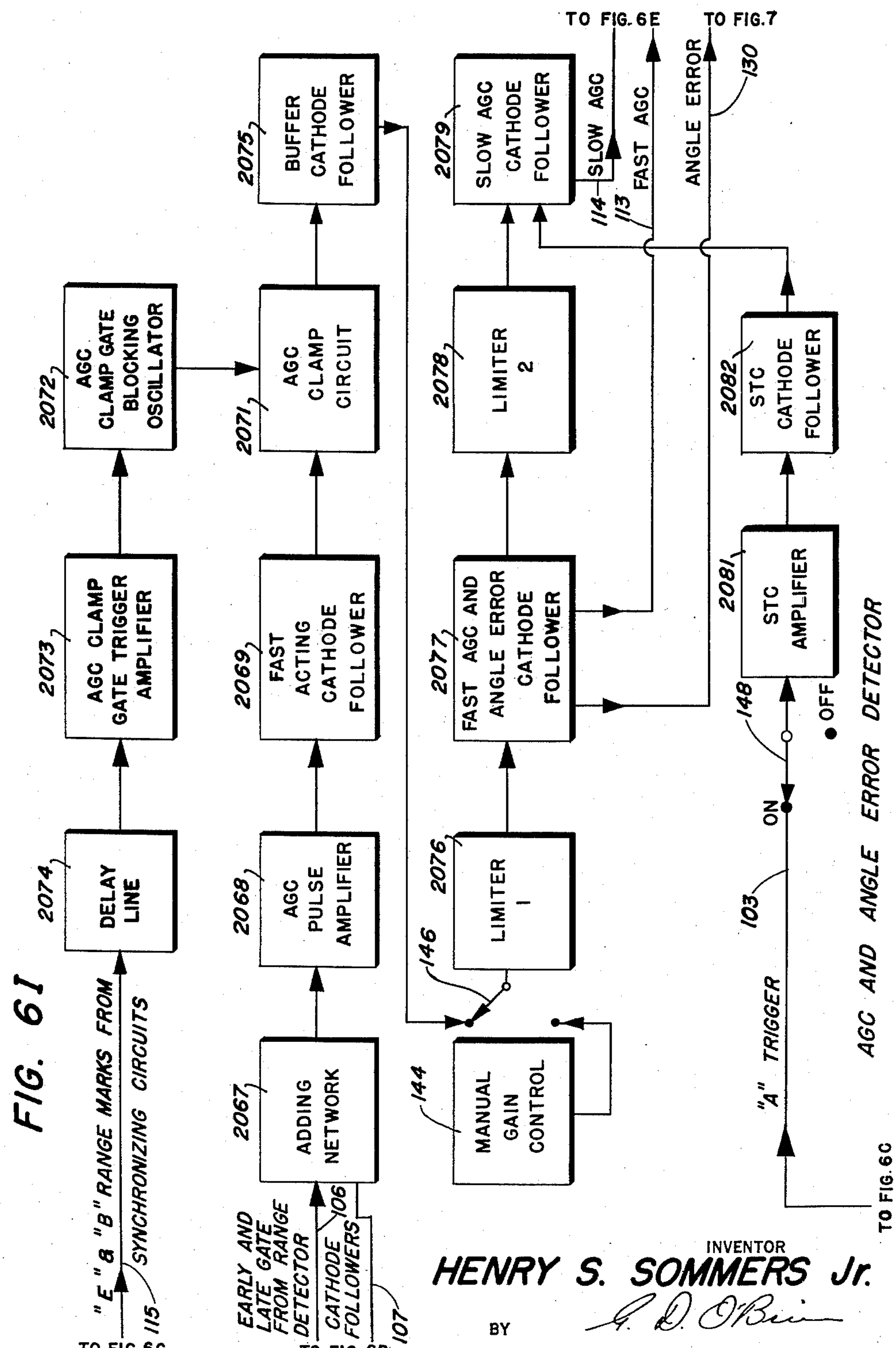

INVENTOR

HENRY S. SOMMERS Jr.

BY

ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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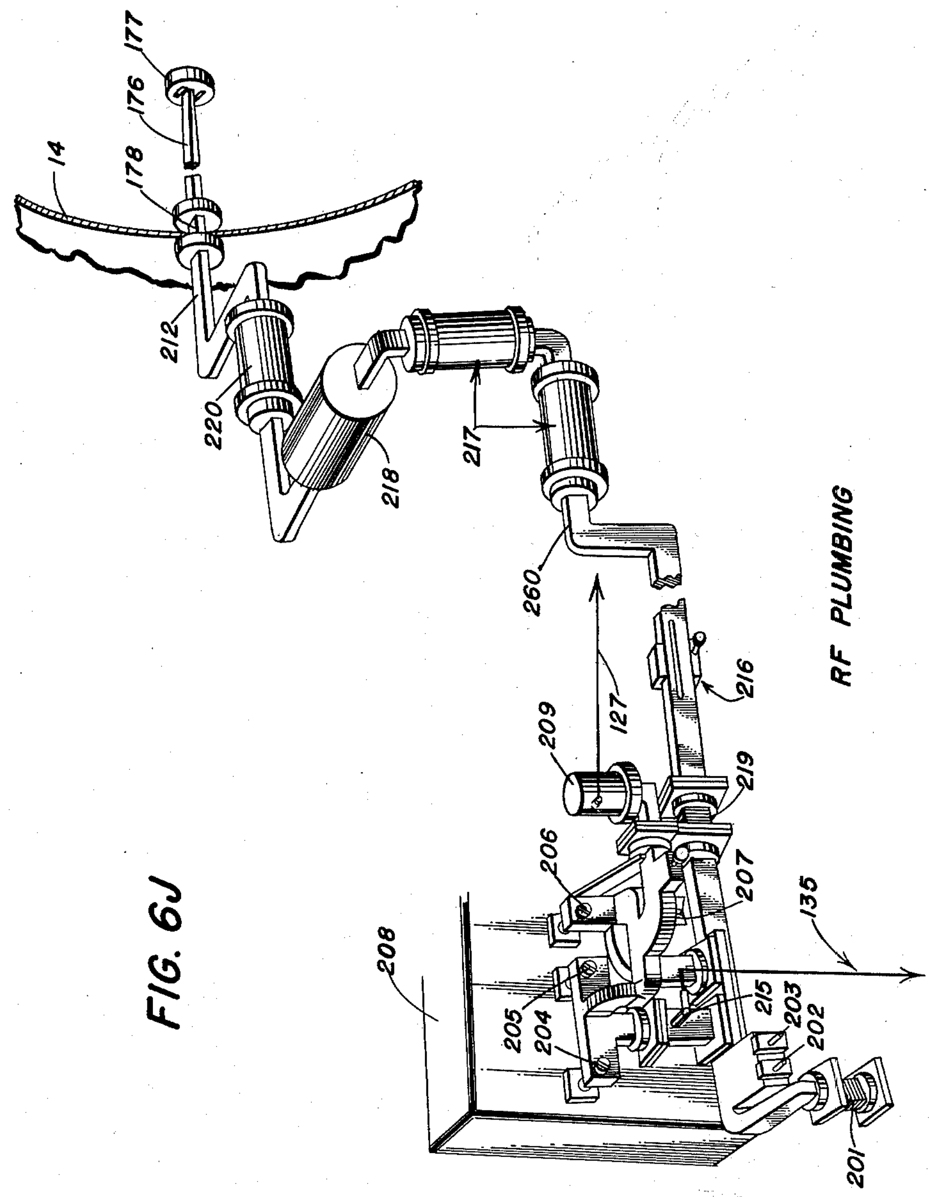

RF PLUMBING

FIG. 6J

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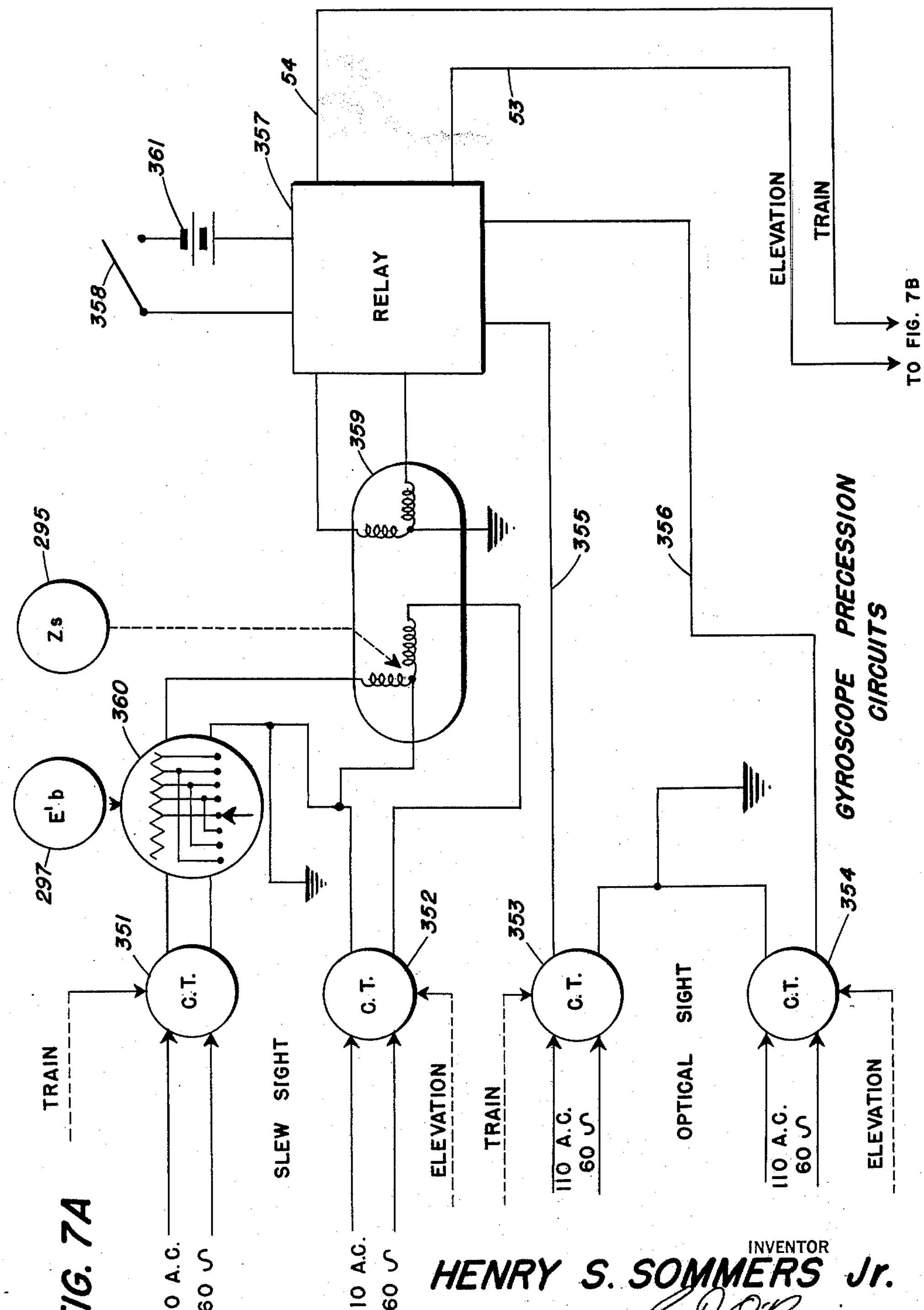

FIG. 7A

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March 19, 1963 H. S. SOMMERS, JR 3,082,415

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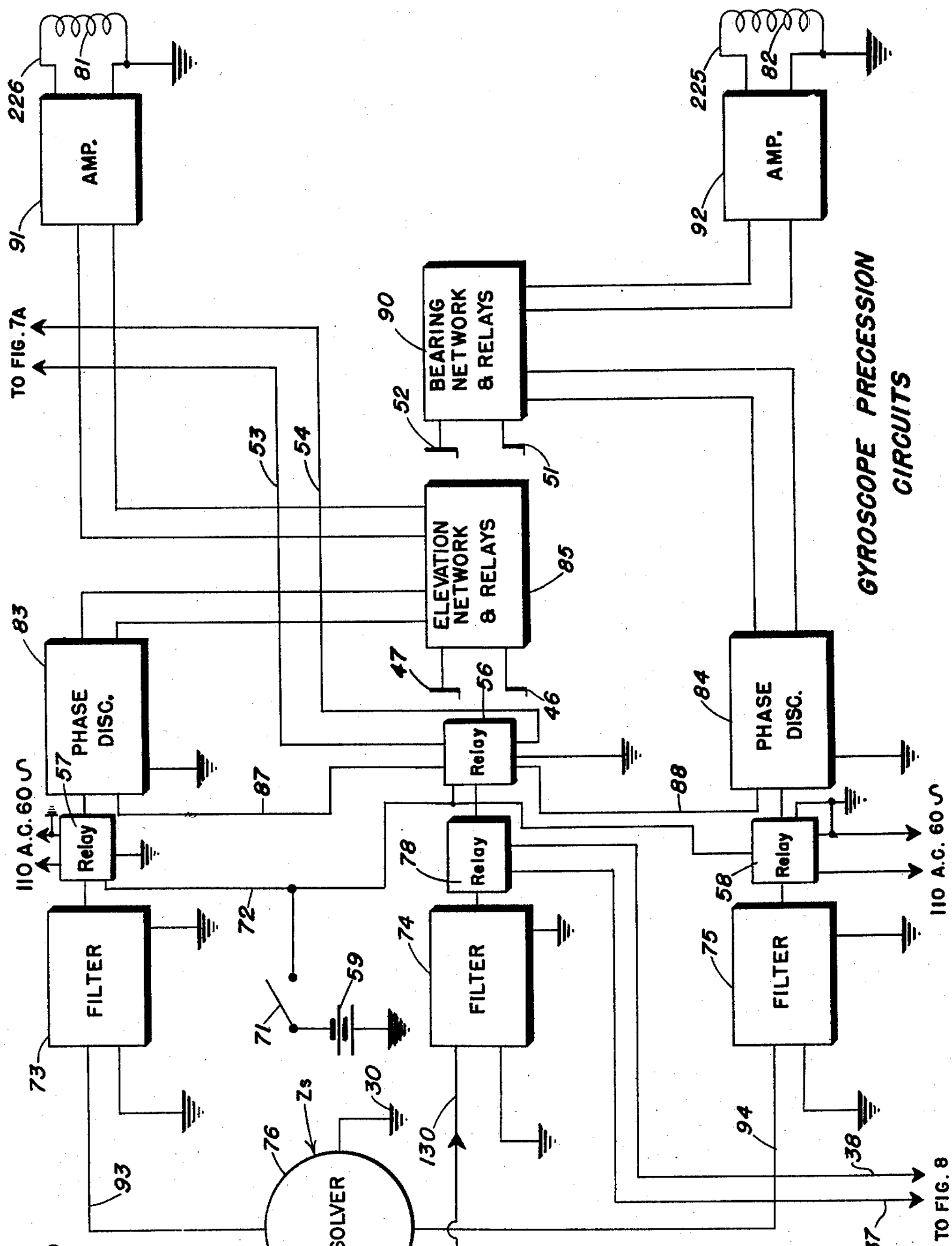

GYROSCOPE PRECESSION CIRCUITS

FIG. 7B

INVENTOR
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ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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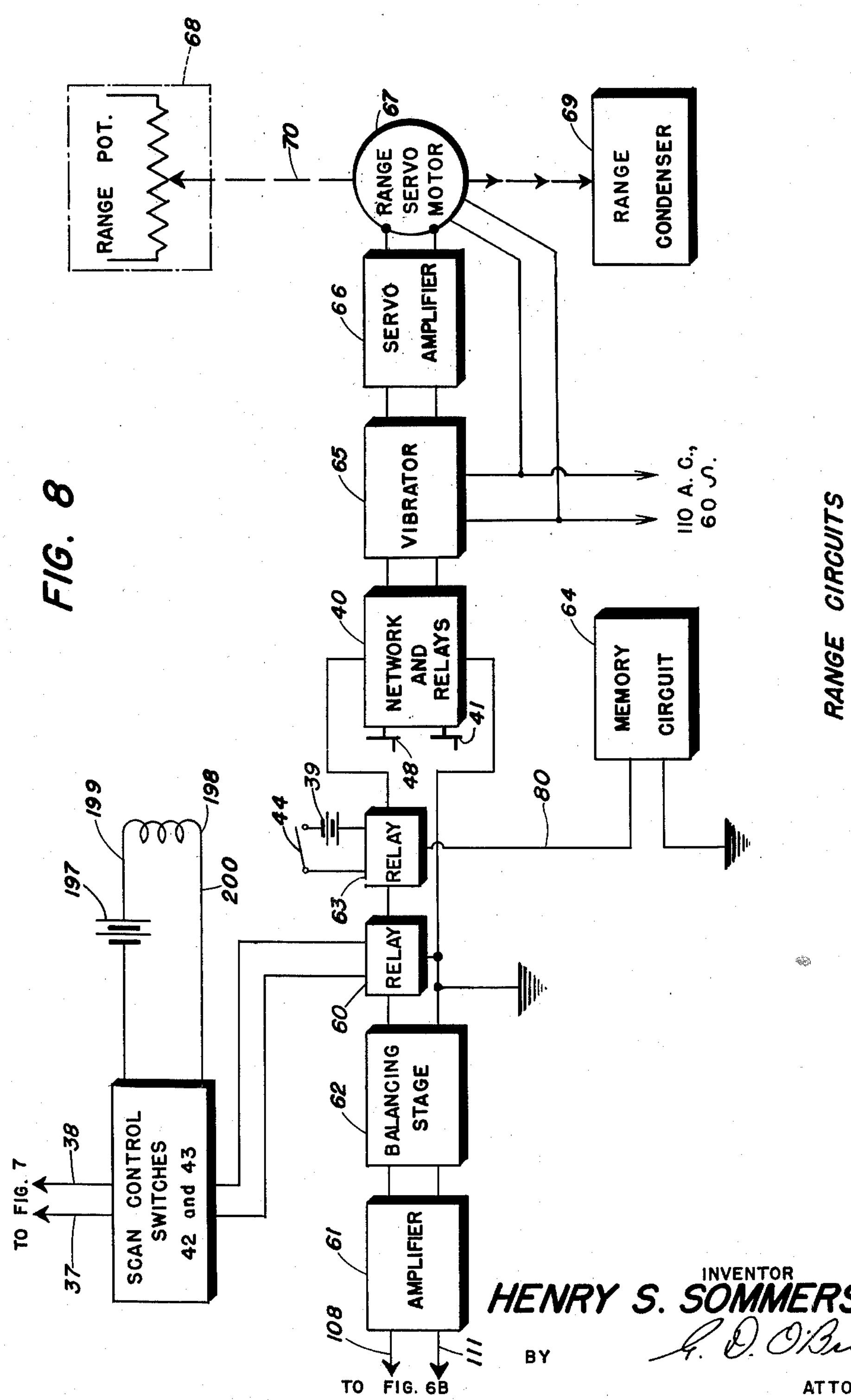
FIG. 8



RANGE CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.

BY G. D. O'Brien

ATTORNEY

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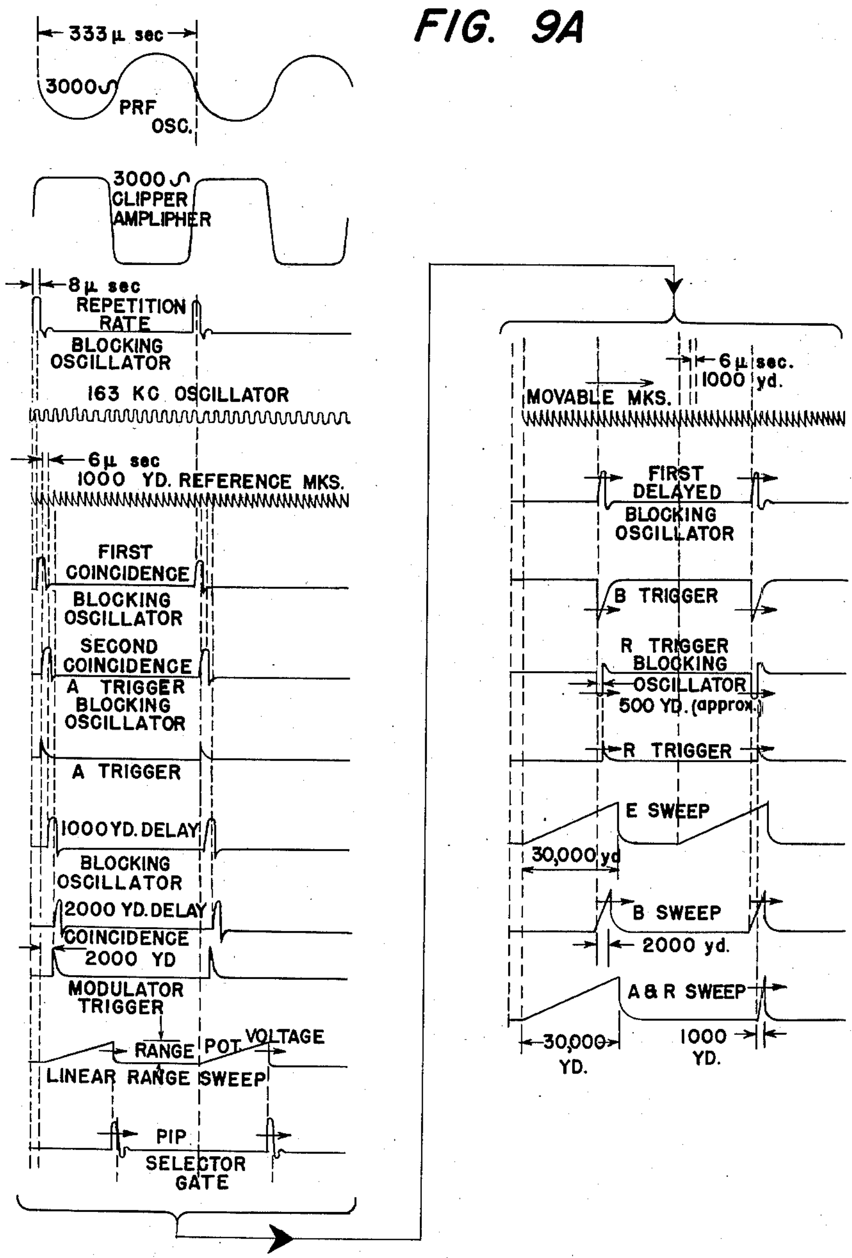
FIG. 9A



TIME CHART

INVENTOR
HENRY S. SOMMERS Jr.
BY R. D. O'Brien
ATTORNEY

FIG. 9B

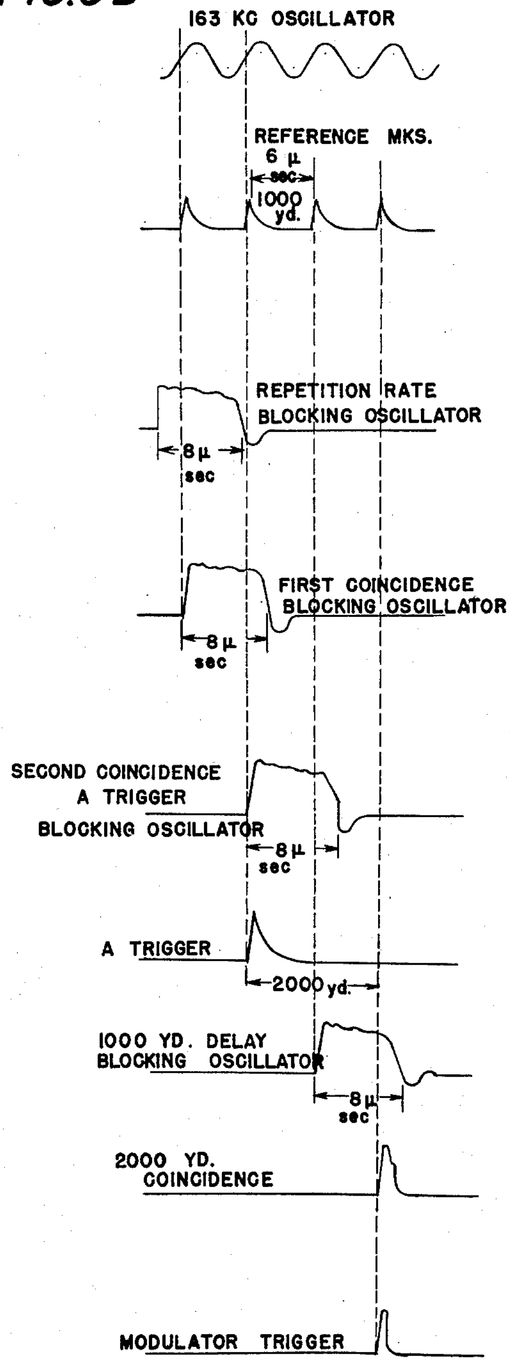
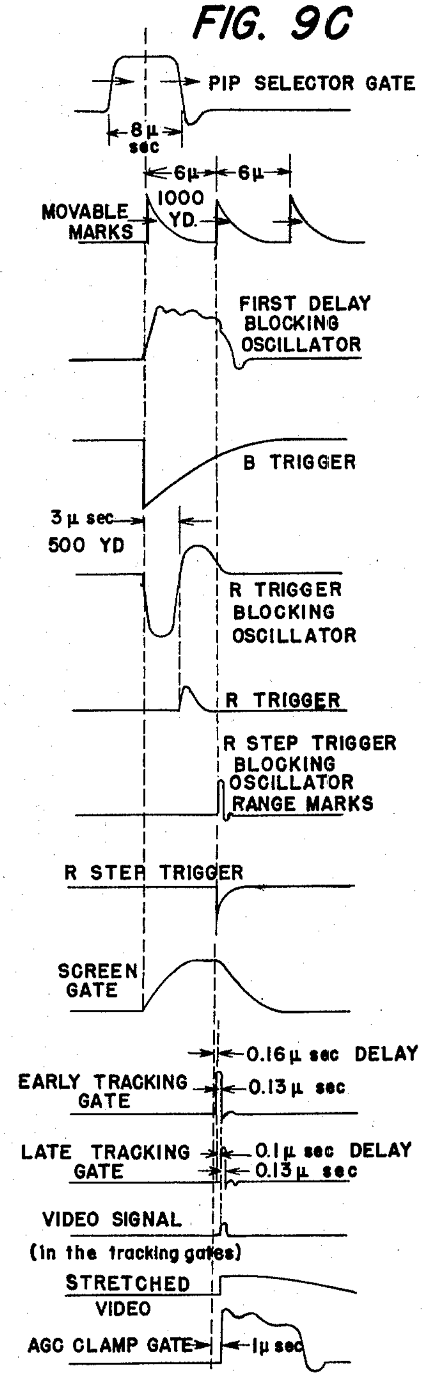


FIG. 9C



INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

METHOD AND APPARATUS OF TARGET ACQUISITION

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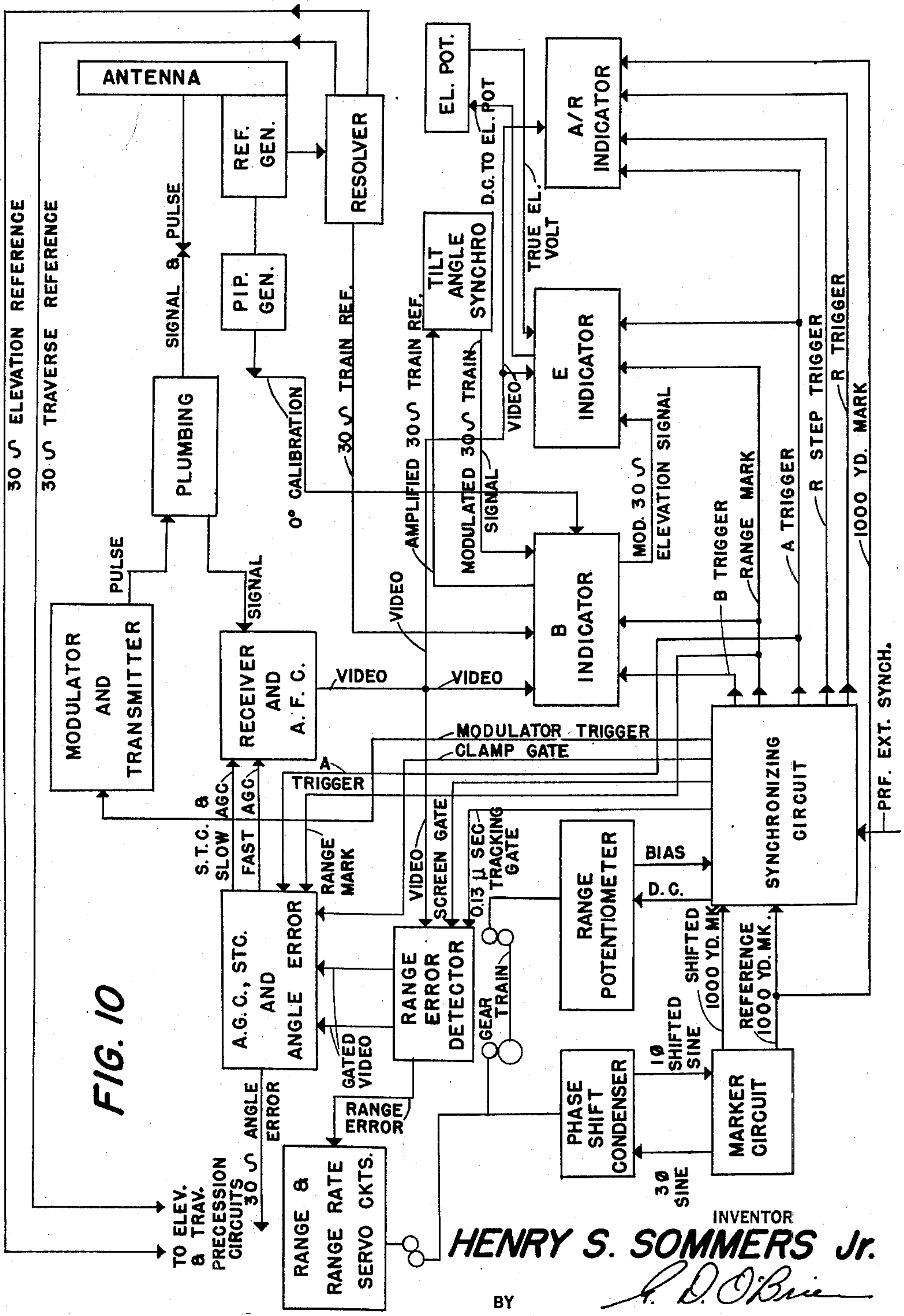
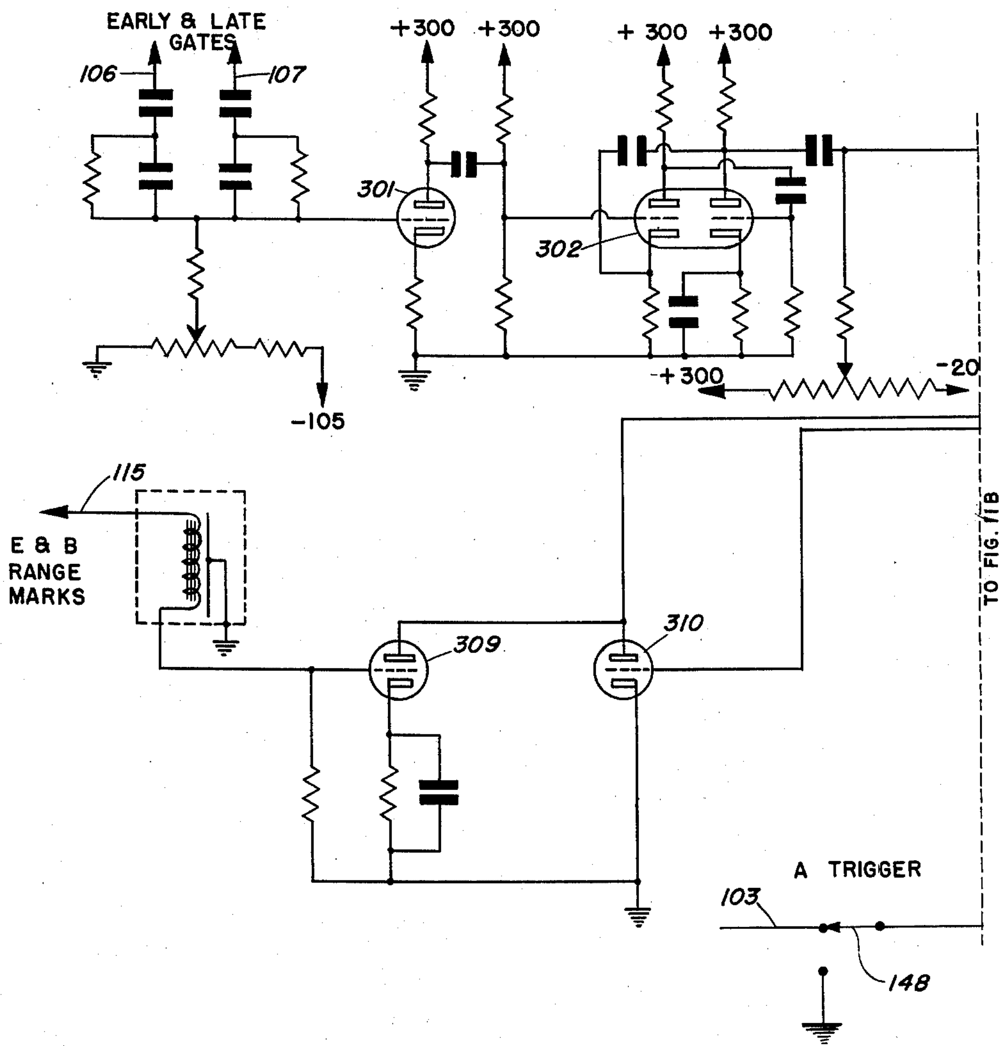


FIG. 10

INVENTOR
HENRY S. SOMMERS Jr.
BY [signature]
ATTORNEY

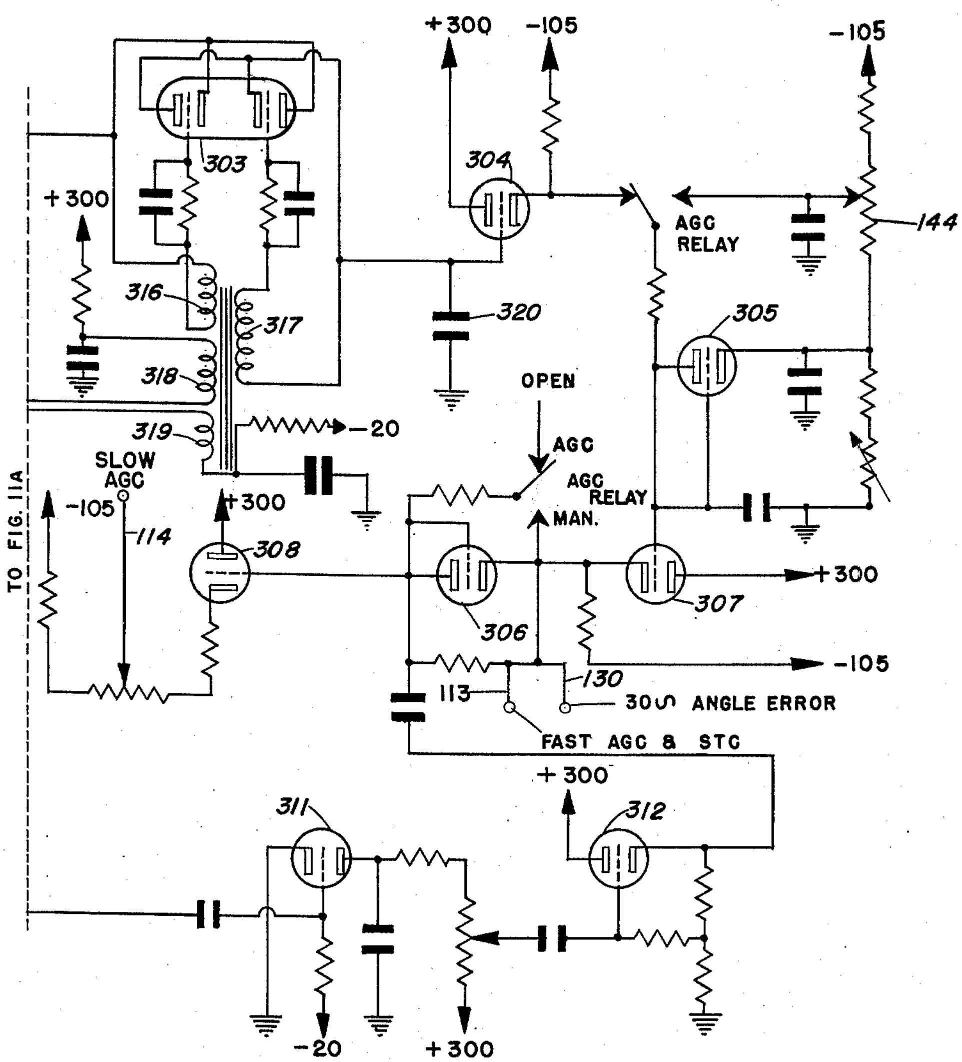
FIG. 11A



AGC & ANGLE ERROR DETECTOR CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

FIG. 11 B



AGC & ANGLE ERROR DETECTOR CIRCUITS

INVENTOR
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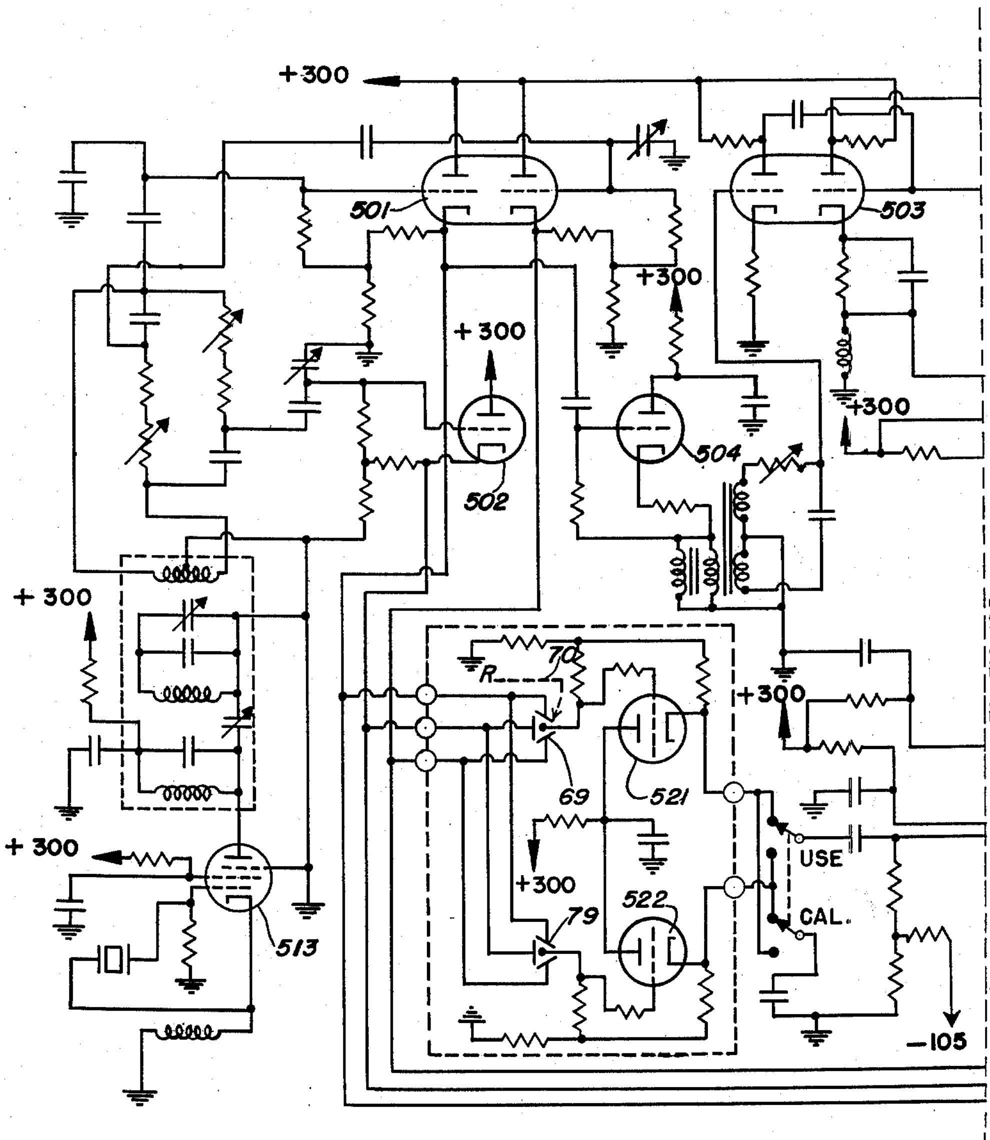
BY [signature]
ATTORNEY

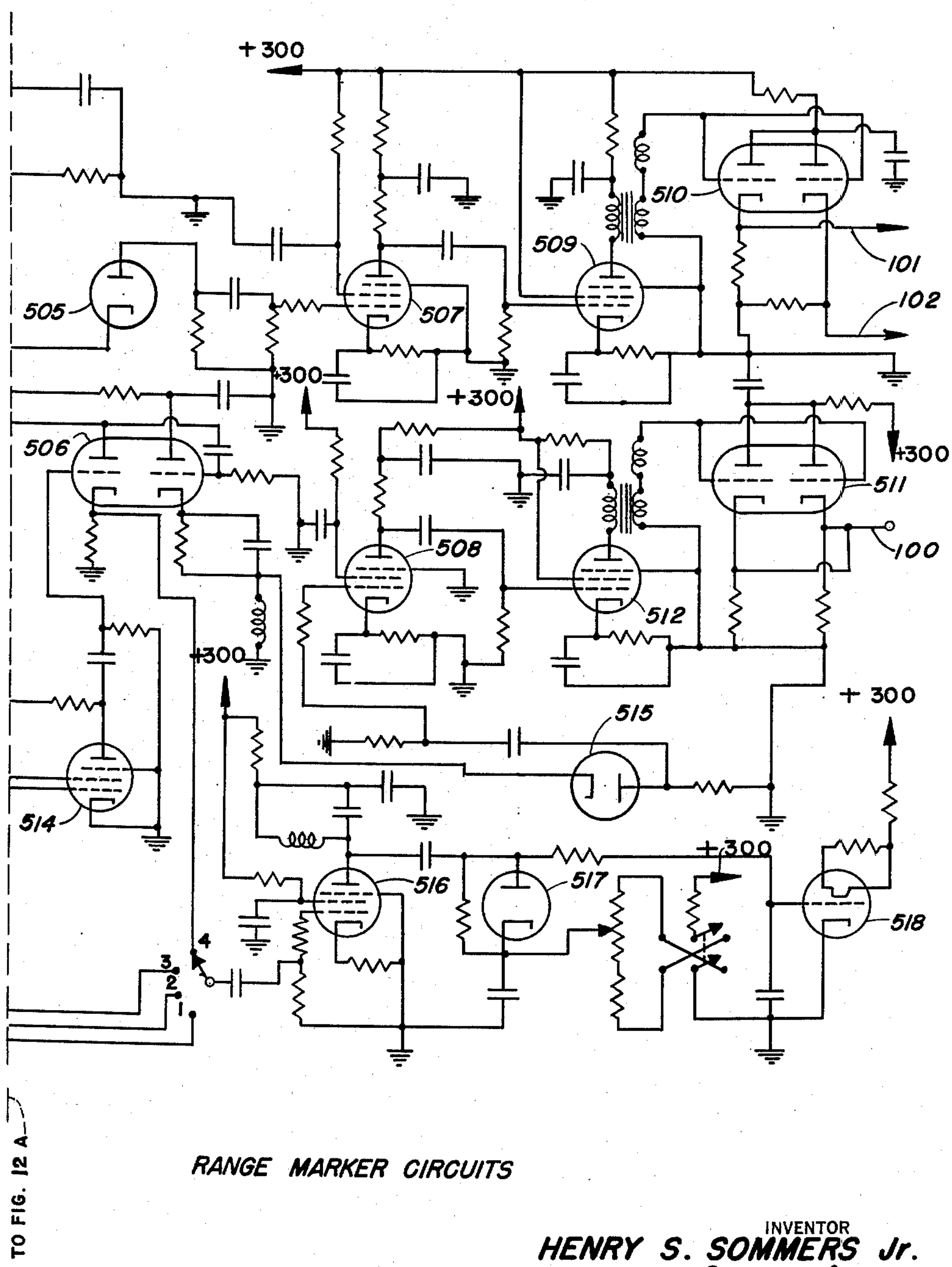
FIG. 12A



RANGE MARKER CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

FIG. 12B



RANGE MARKER CIRCUITS

INVENTOR
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BY G. D. O'Brien

ATTORNEY

March 19, 1963 H. S. SOMMERS, JR 3,082,415

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FIG. 20

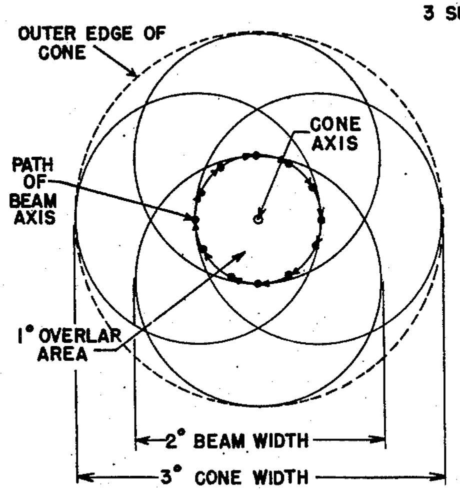


FIG. 21

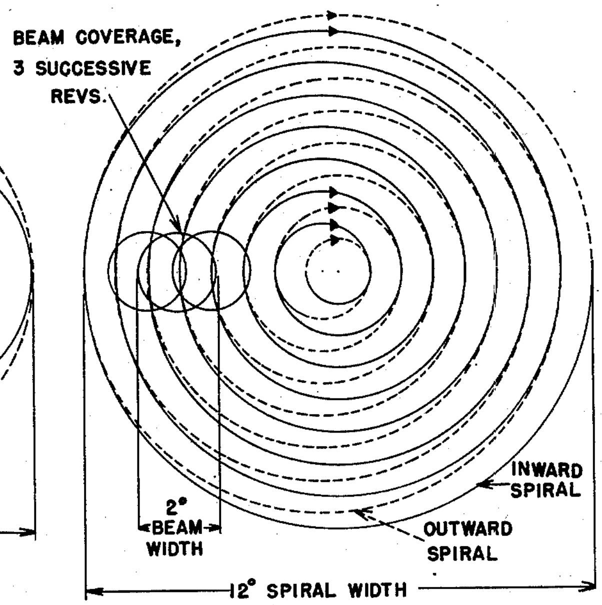
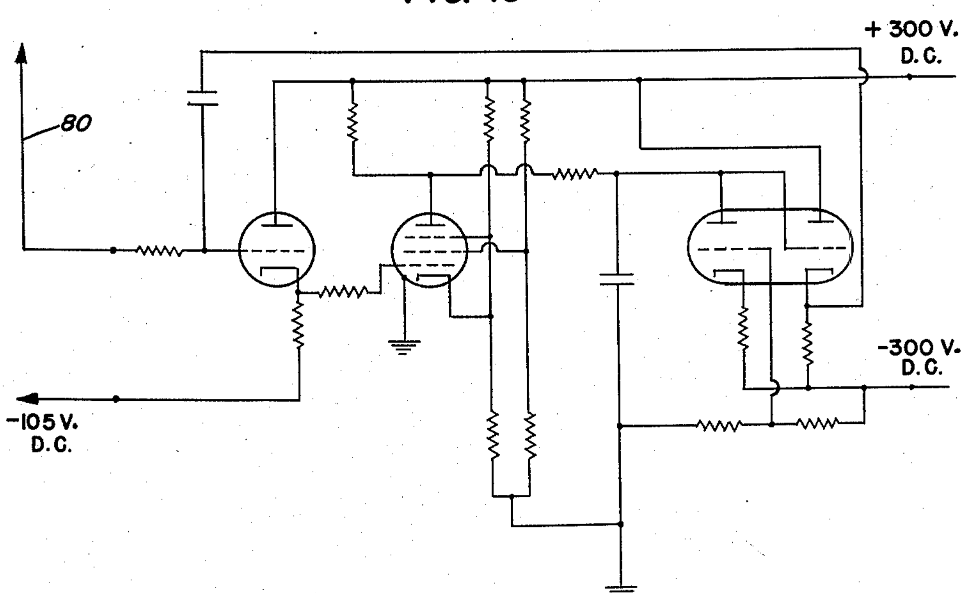


FIG. 13

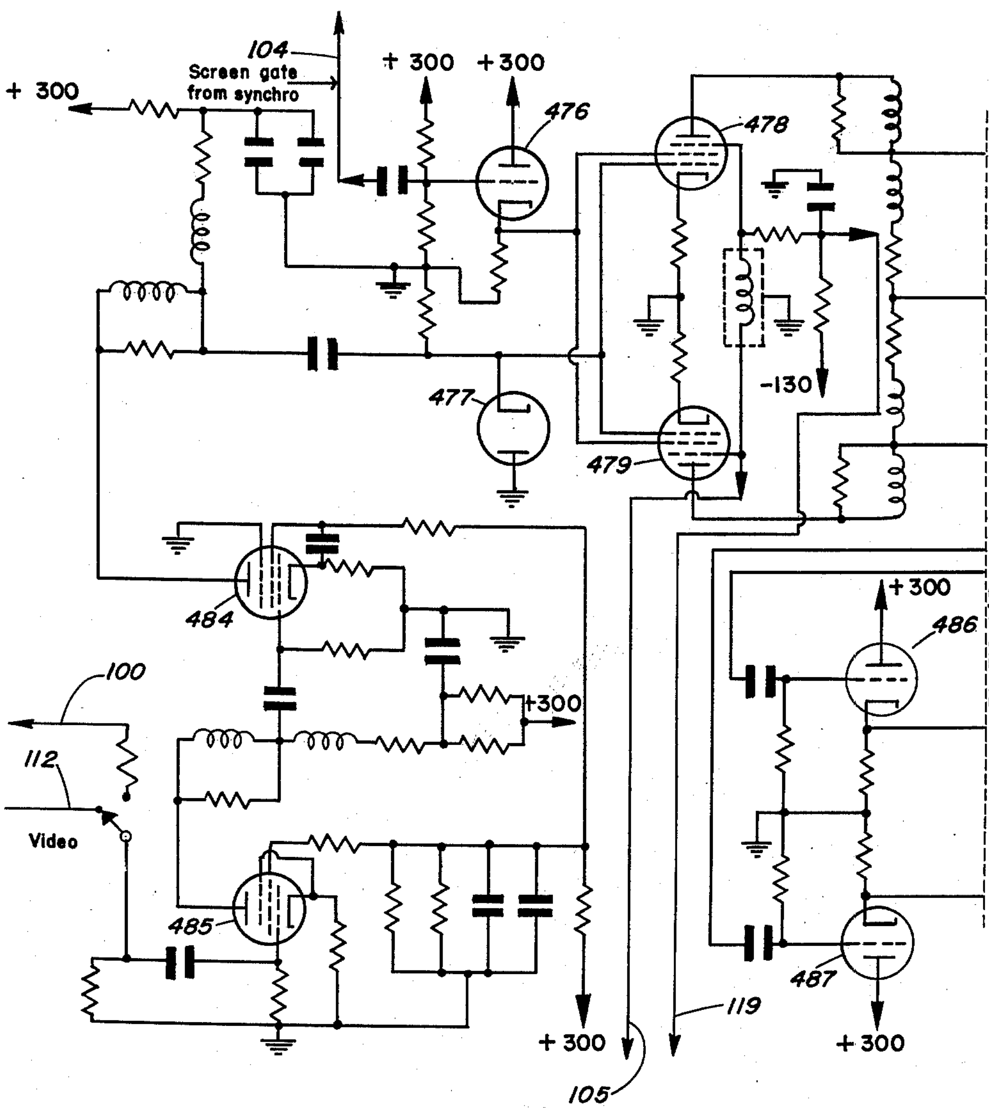


INVENTOR
HENRY S. SOMMERS Jr.

BY G. D. O'Brien

ATTORNEY

FIG. 14A



RANGE ERROR DETECTOR CIRCUITS

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March 19, 1963 H. S. SOMMERS, JR 3,082,415

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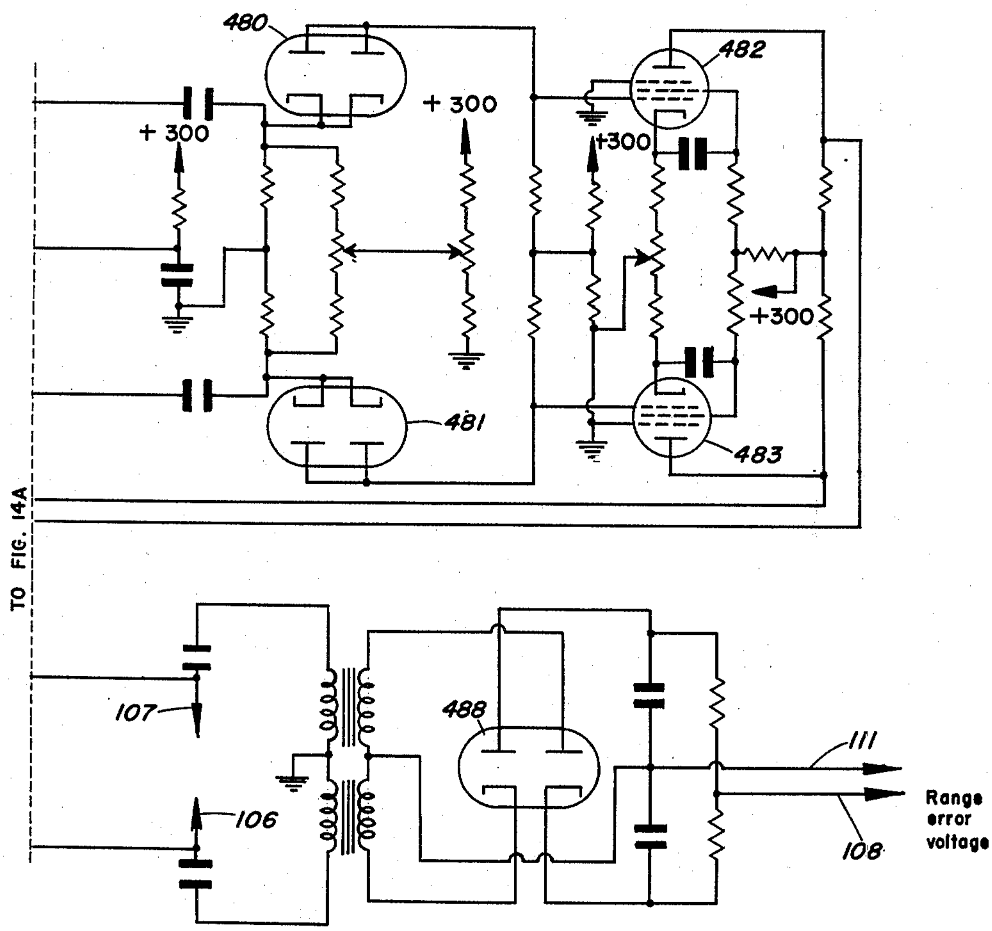
FIG. 14B



RANGE ERROR DETECTOR CIRCUITS

INVENTOR
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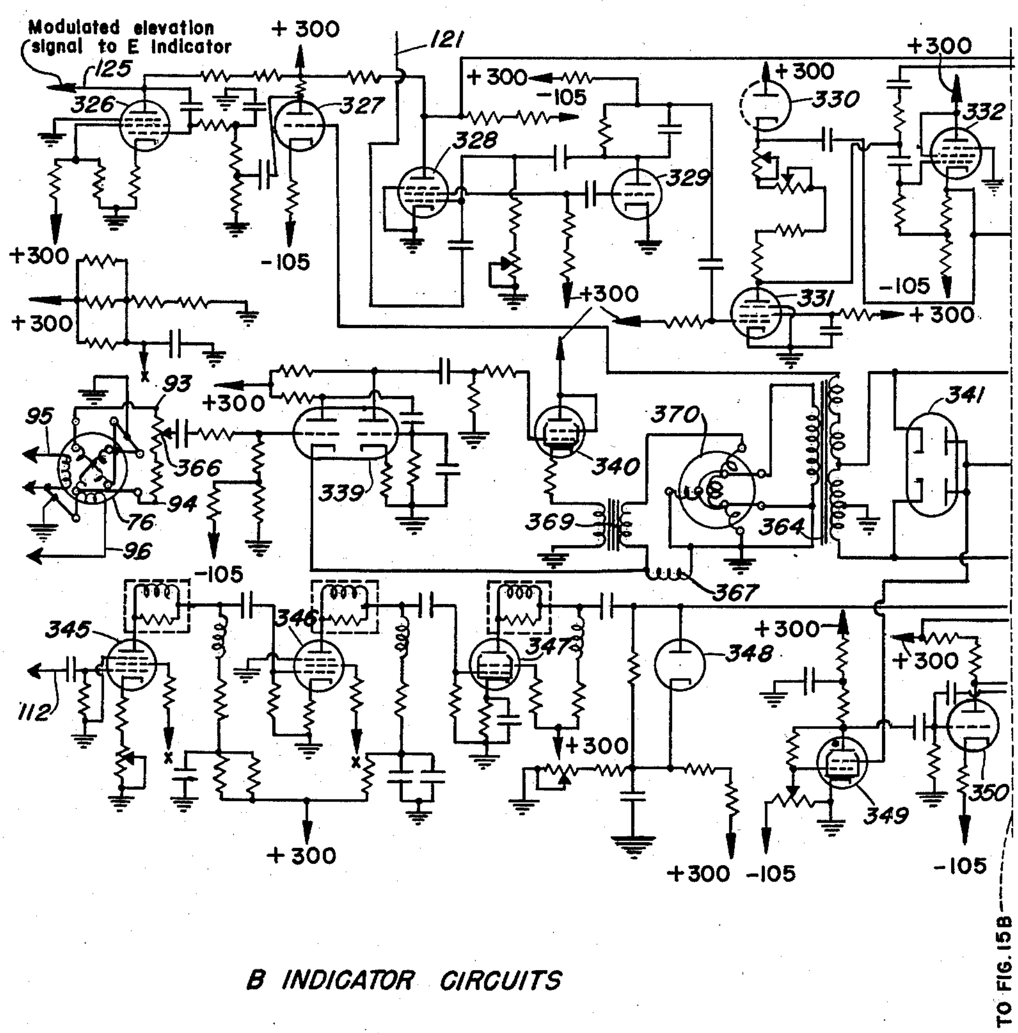
BY G. D. O'Brien
ATTORNEY

FIG. 15A



B INDICATOR CIRCUITS

INVENTOR
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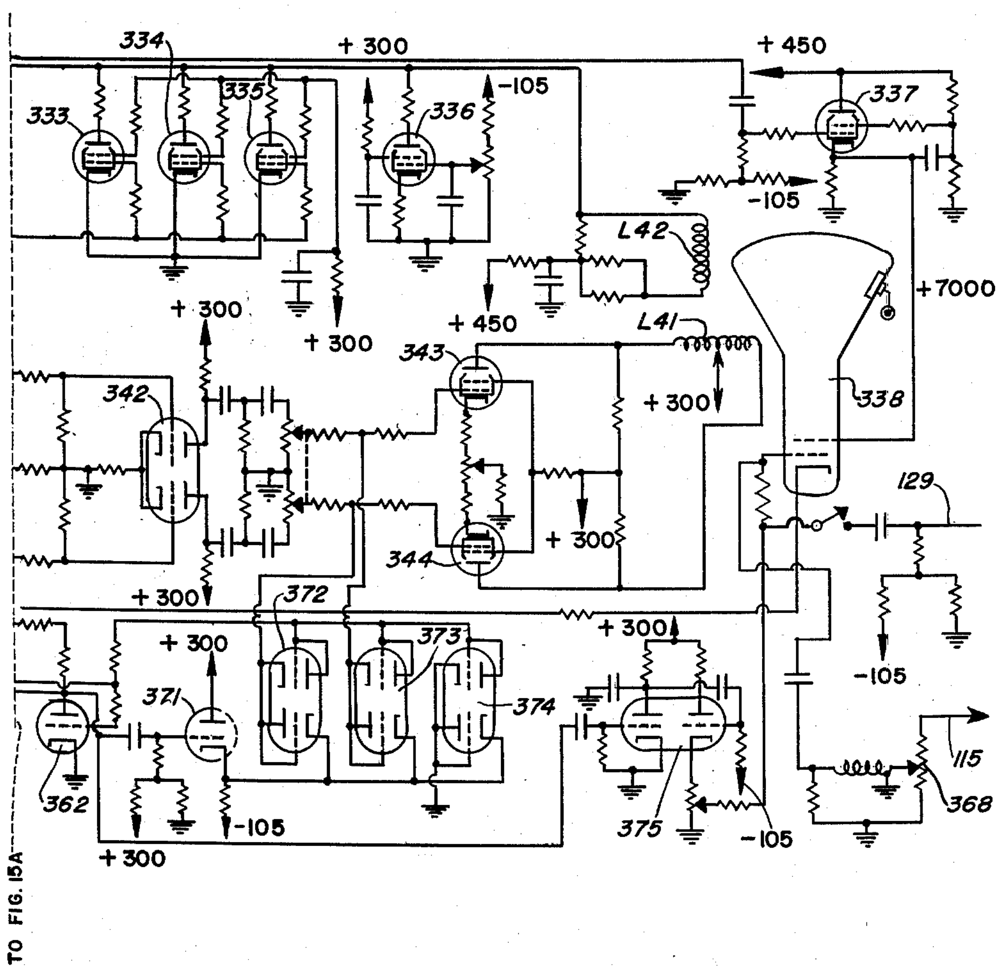
FIG. 15B



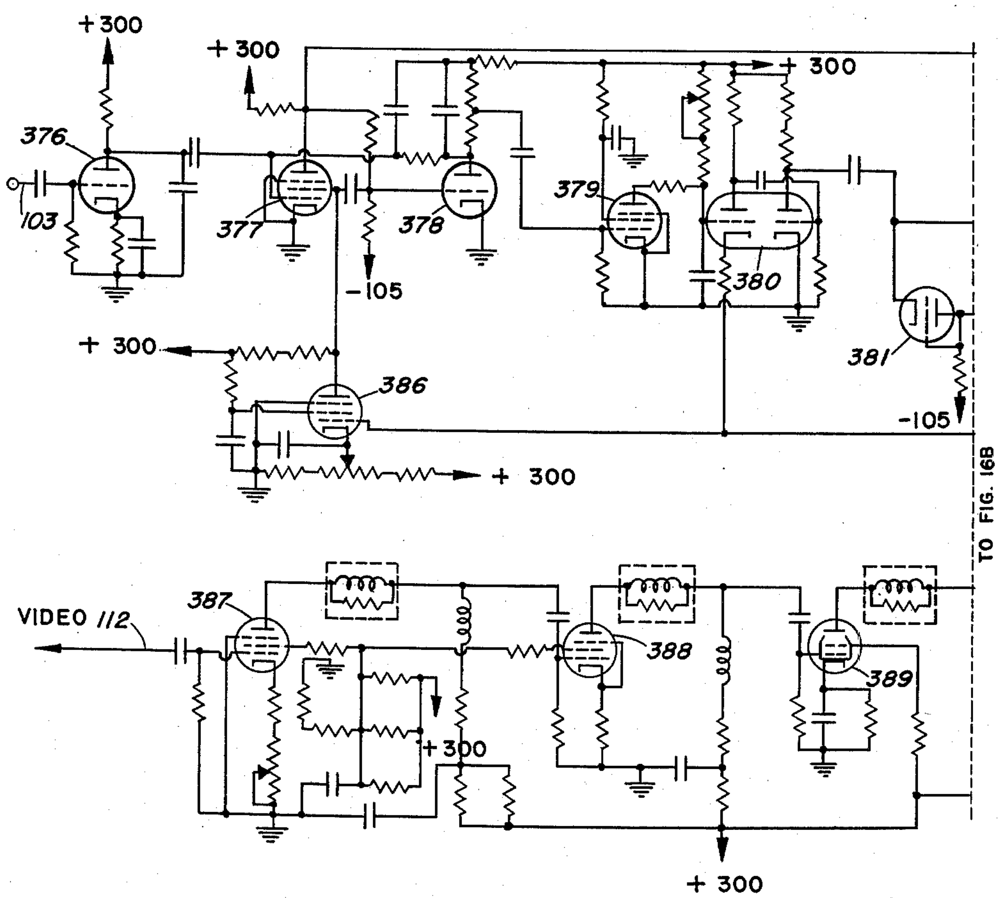
B INDICATOR CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.

BY G. D. O'Brien

ATTORNEY

FIG. 16A



E INDICATOR CIRCUITS

INVENTOR
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March 19, 1963 H. S. SOMMERS, JR 3,082,415

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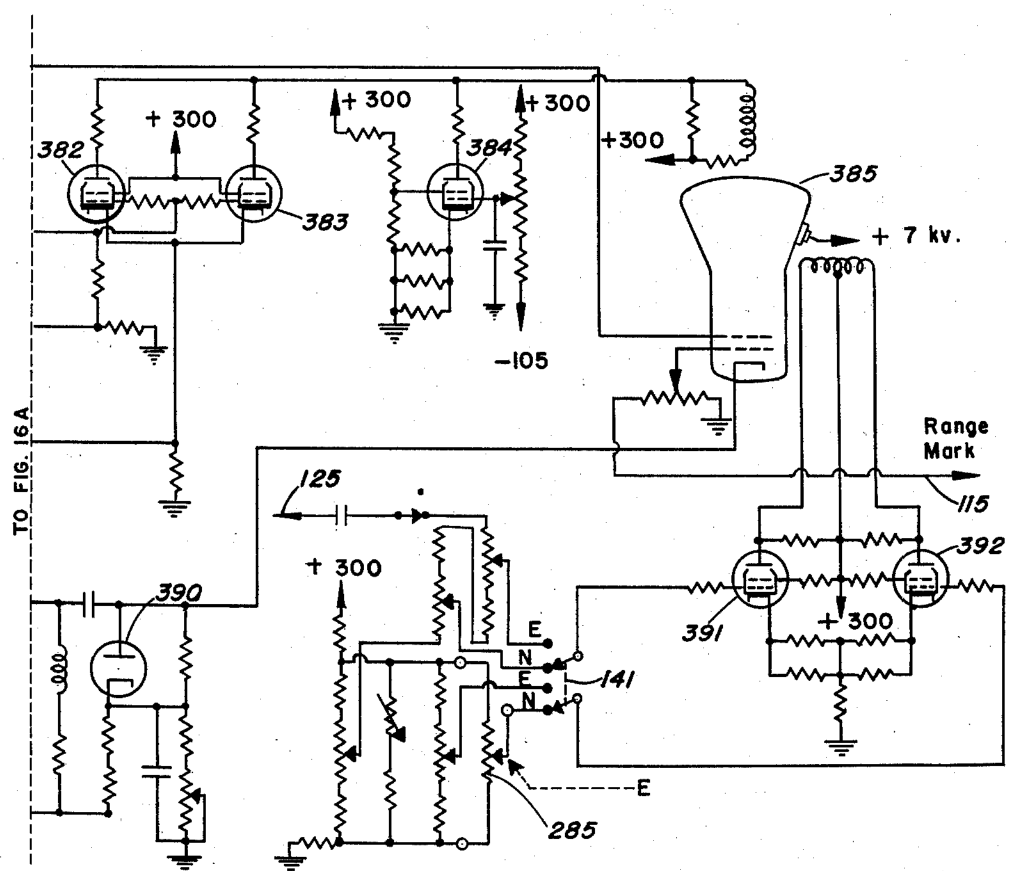
FIG. 16 B



E INDICATOR CIRCUITS

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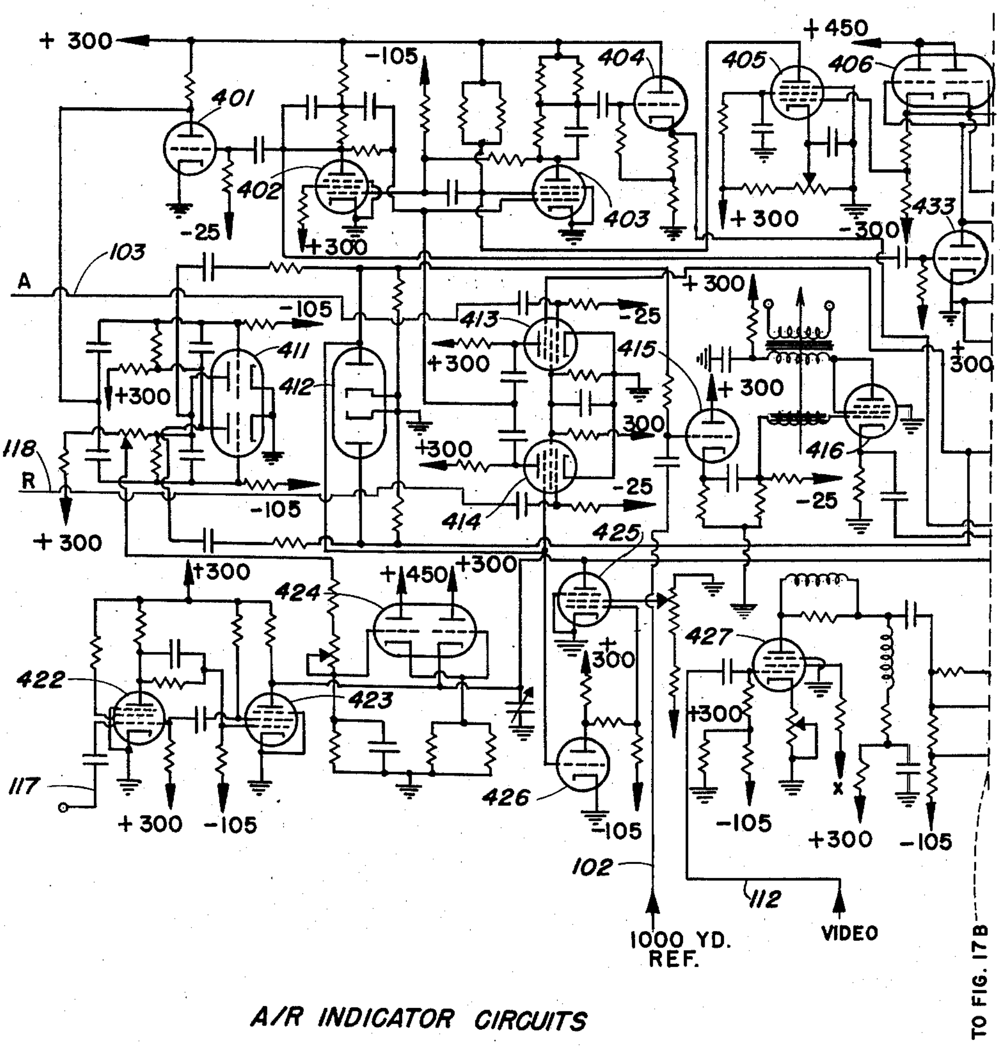
FIG. 17A



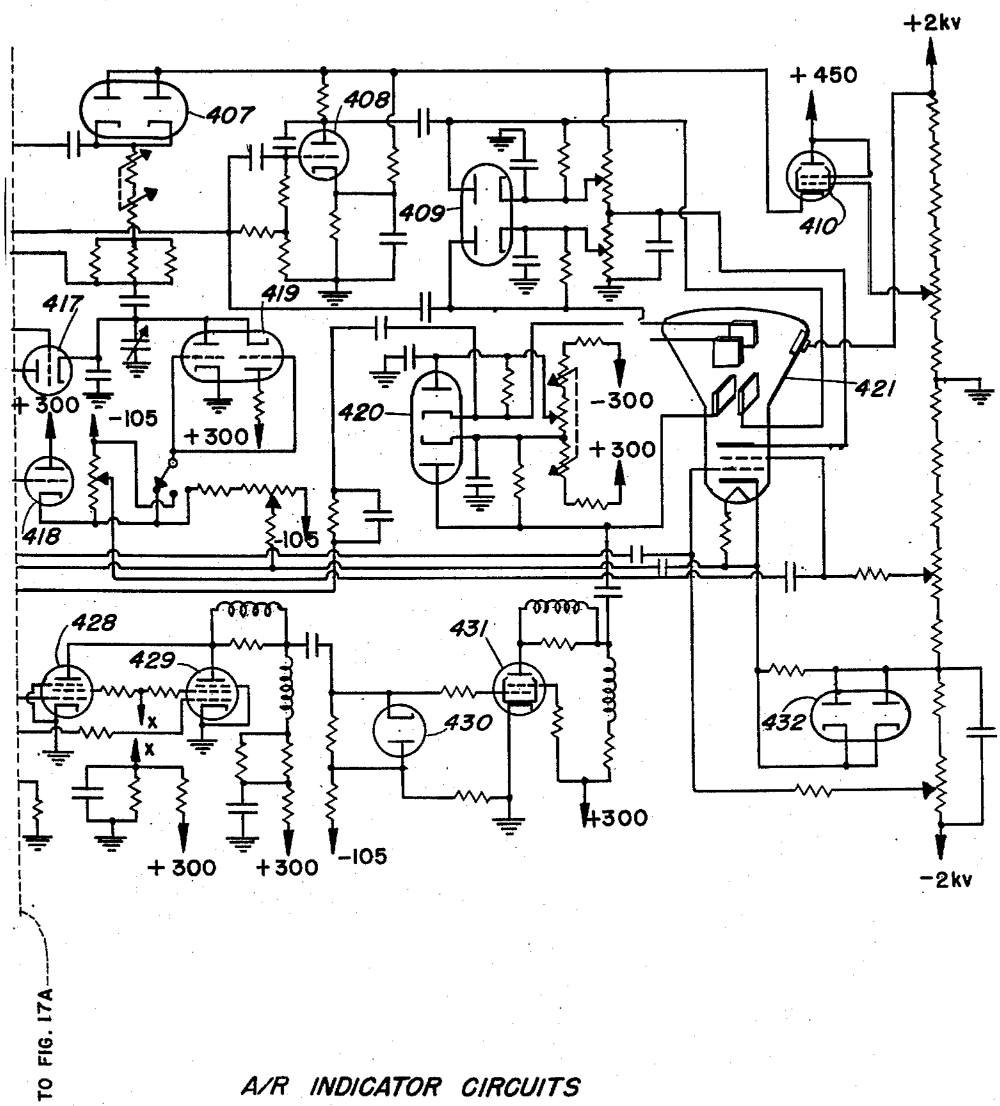
A/R INDICATOR CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.

BY [signature]

ATTORNEY

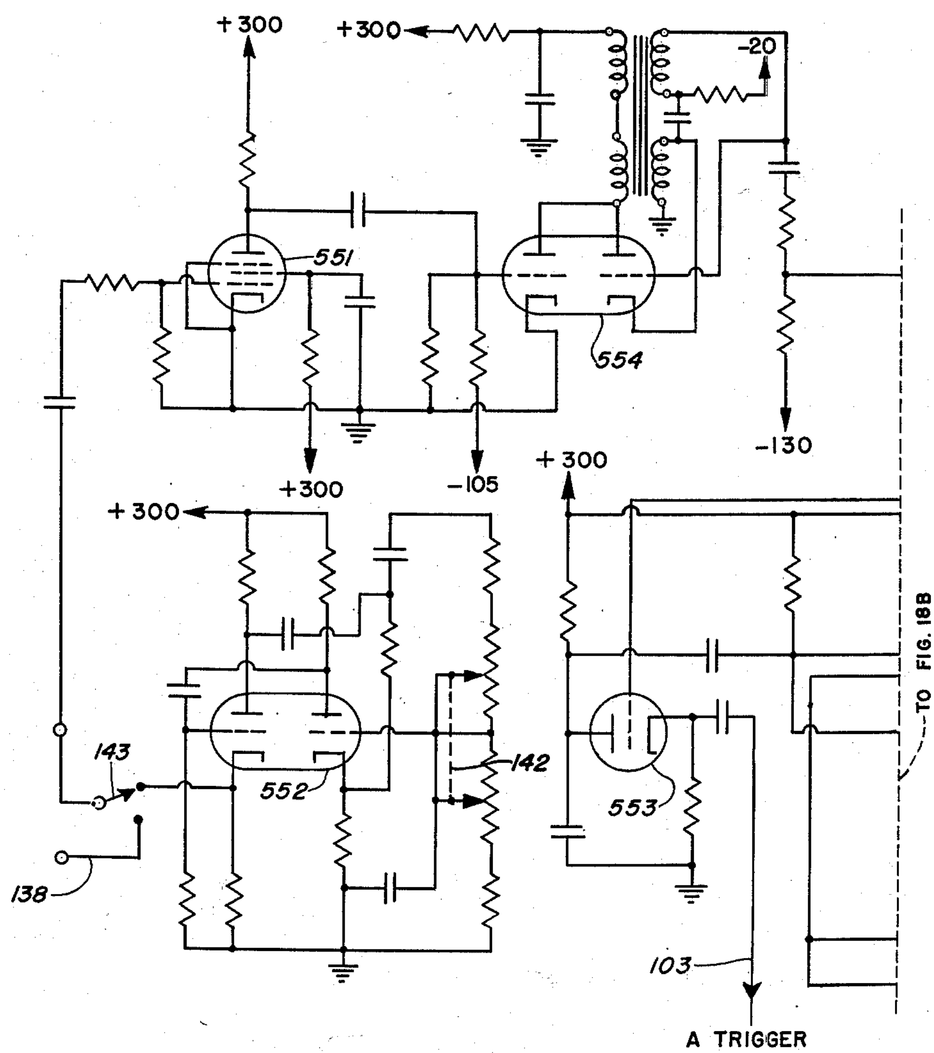
FIG. 17B



A/R INDICATOR CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

FIG. 18A



SYNCHRONIZER CIRCUITS

INVENTOR
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BY G. D. O'Brien
ATTORNEY

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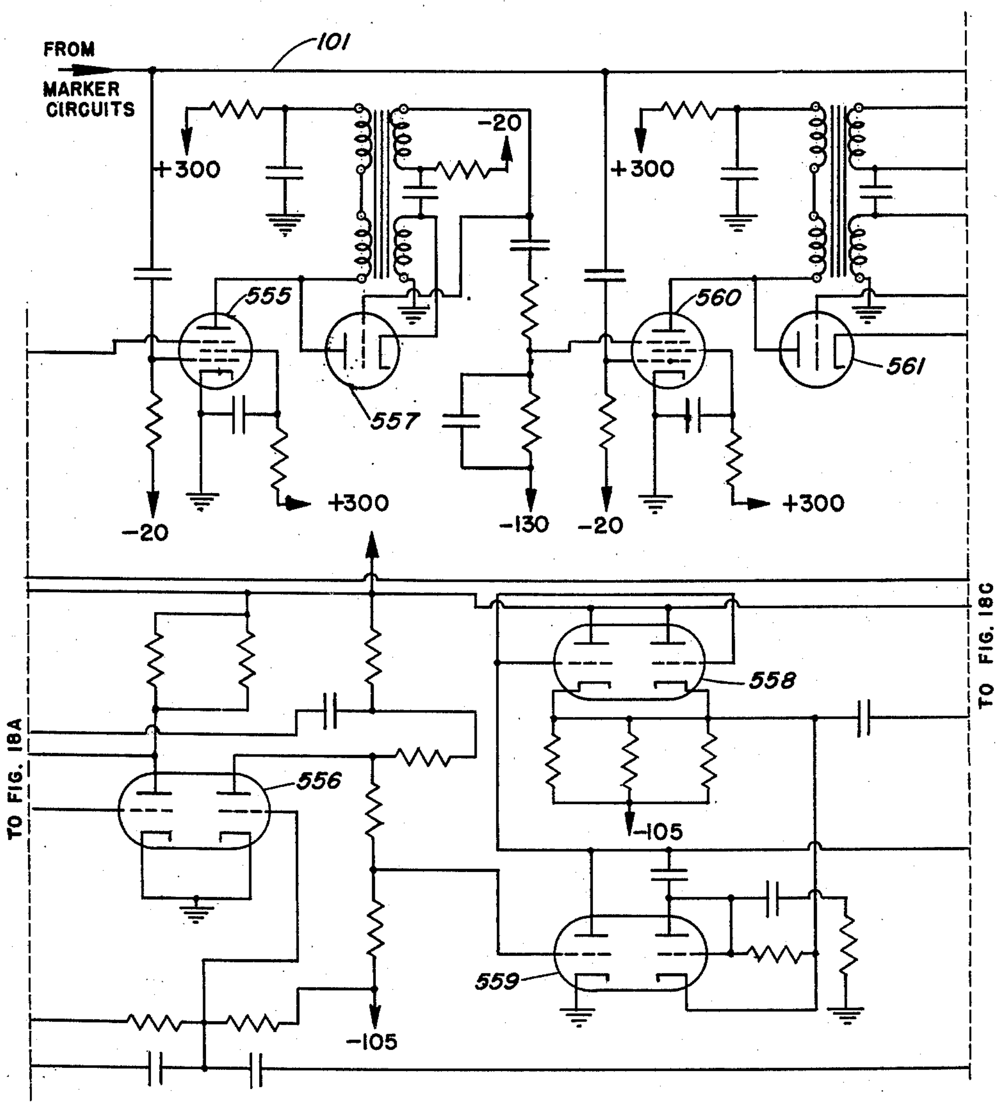
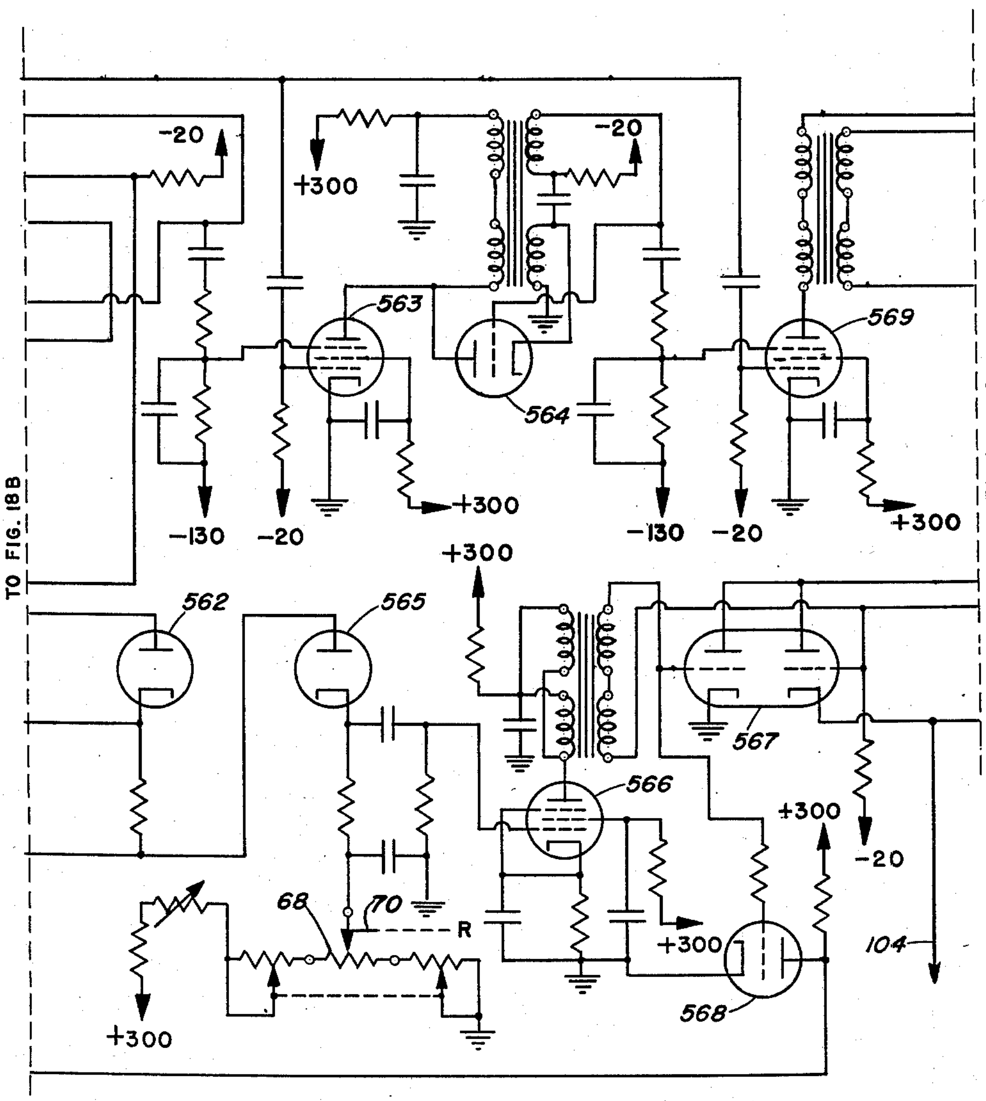
FIG. 18B



SYNCHRONIZER CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

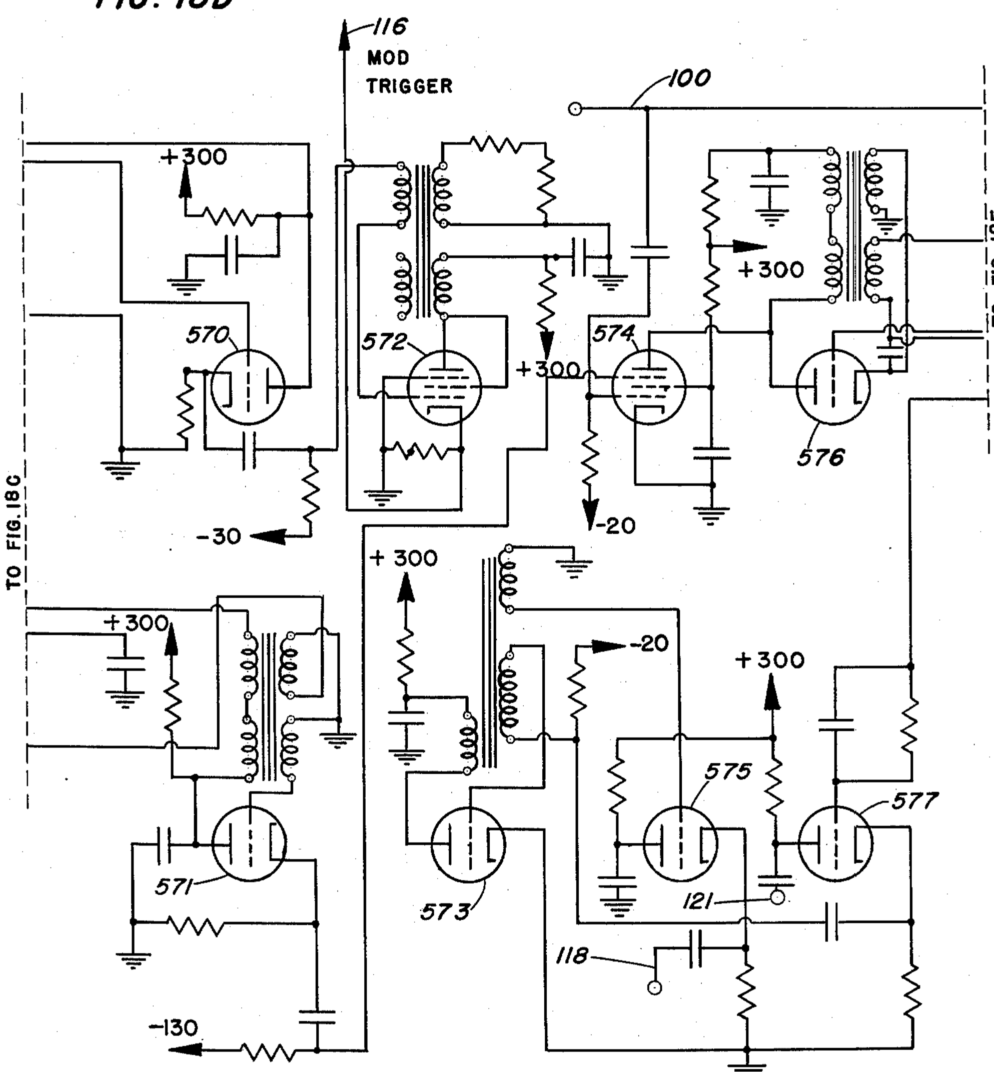
FIG. 18 C



SYNCHRONIZER CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

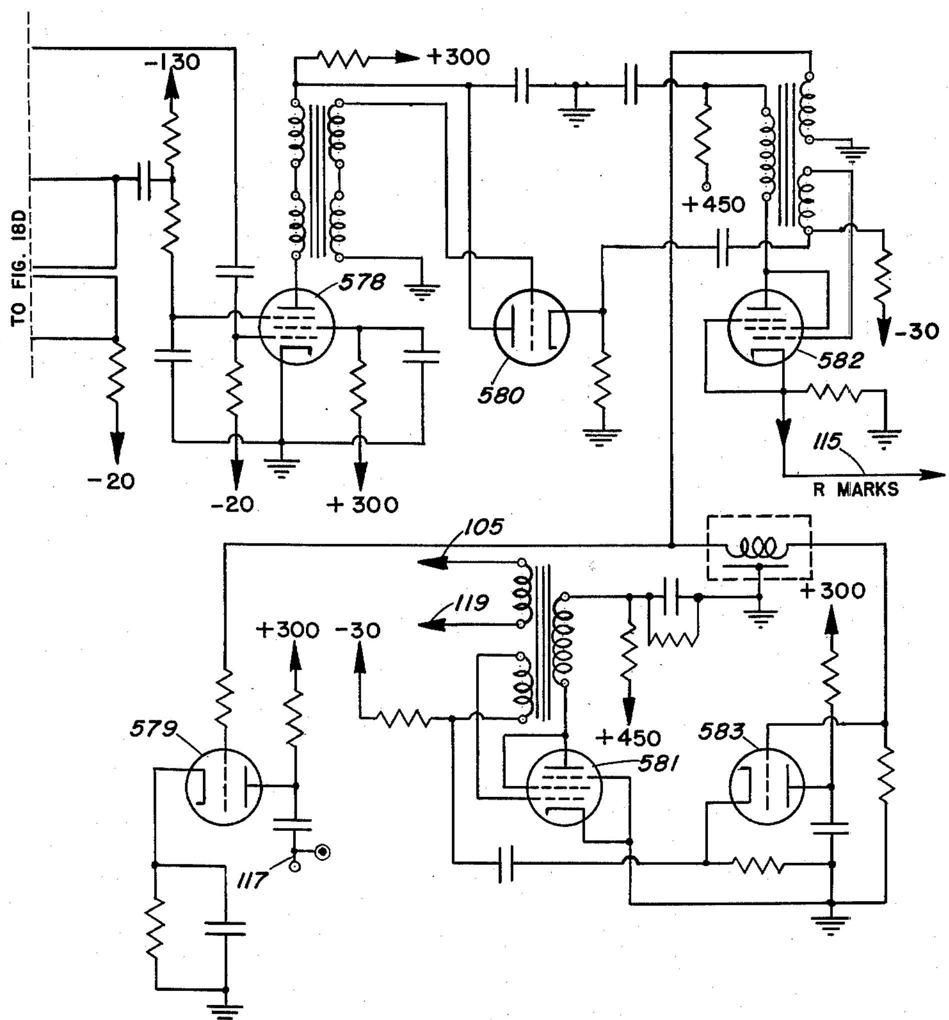
FIG. 18D



SYNCHRONIZER CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

FIG. 18E



SYNCHRONIZER CIRCUITS

INVENTOR
HENRY S. SOMMERS Jr.
BY
ATTORNEY

March 19, 1963 H. S. SOMMERS, JR 3,082,415

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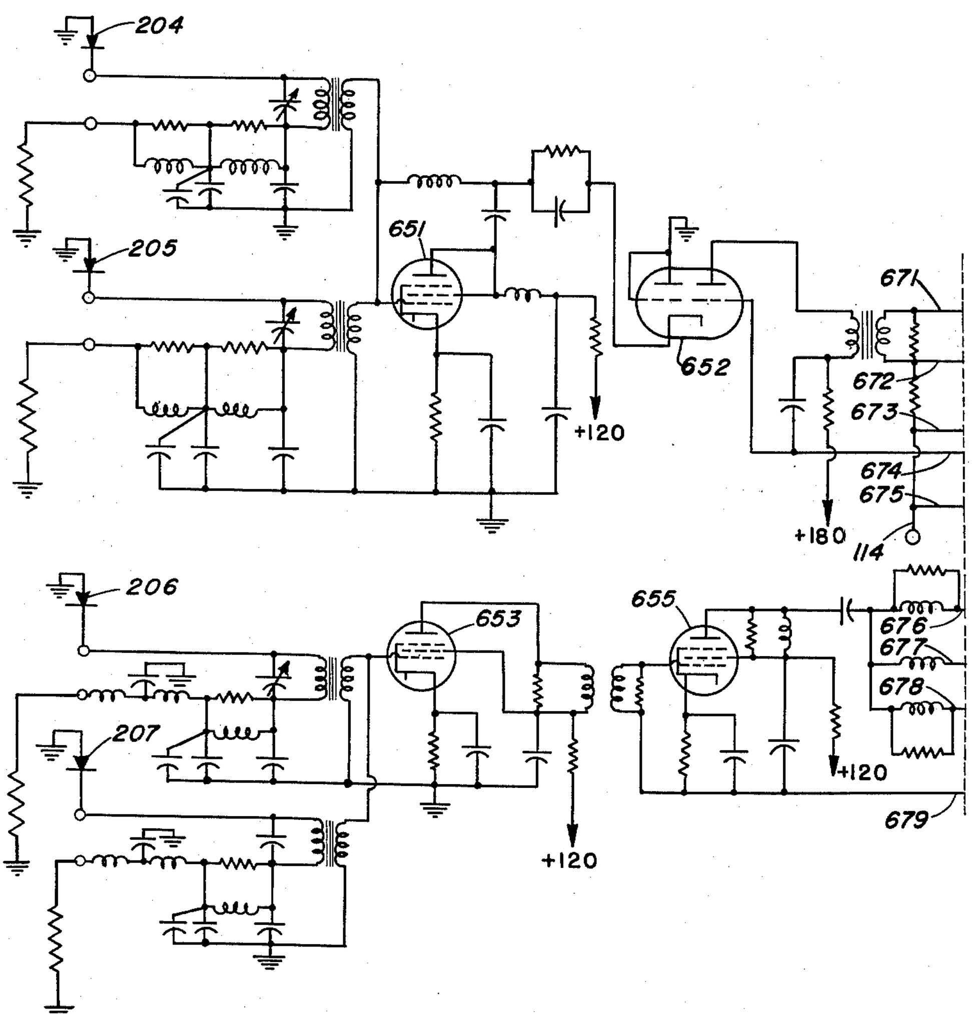
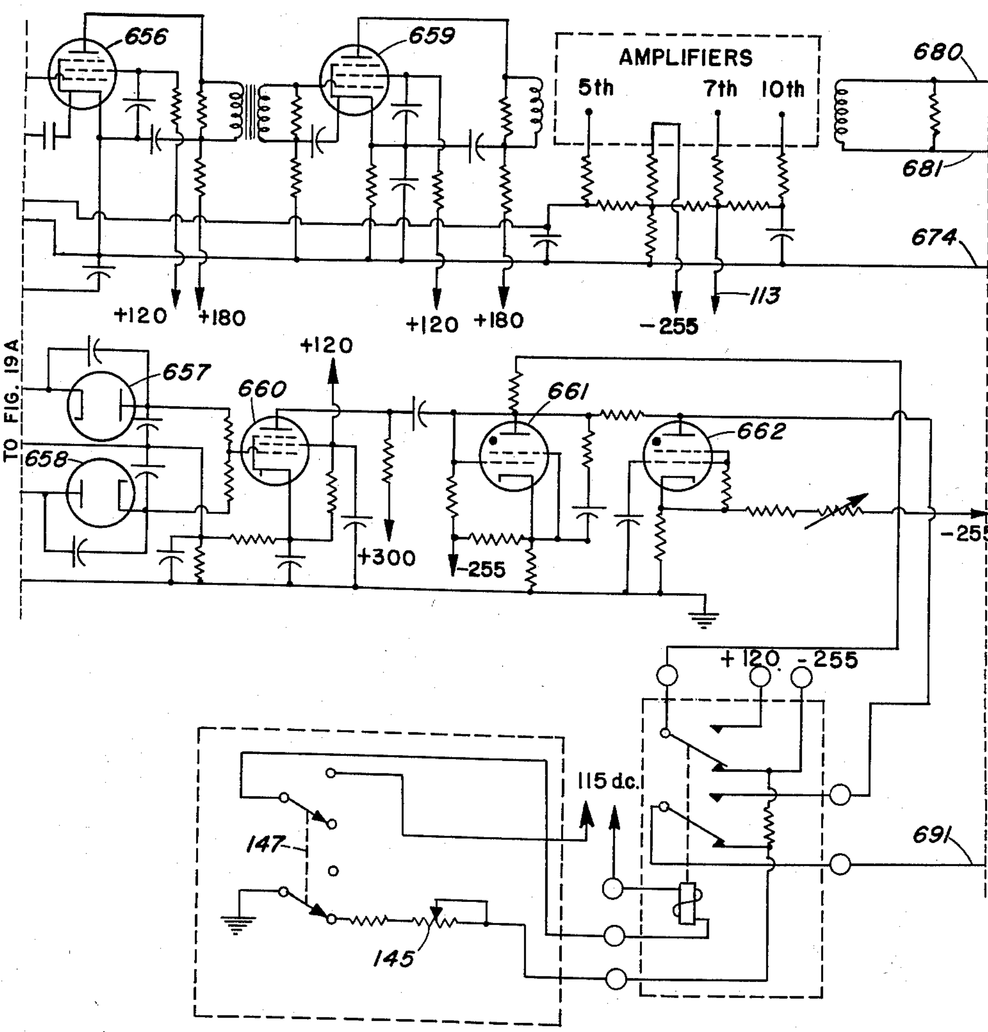
FIG. 19A



RECEIVER CIRCUIT

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

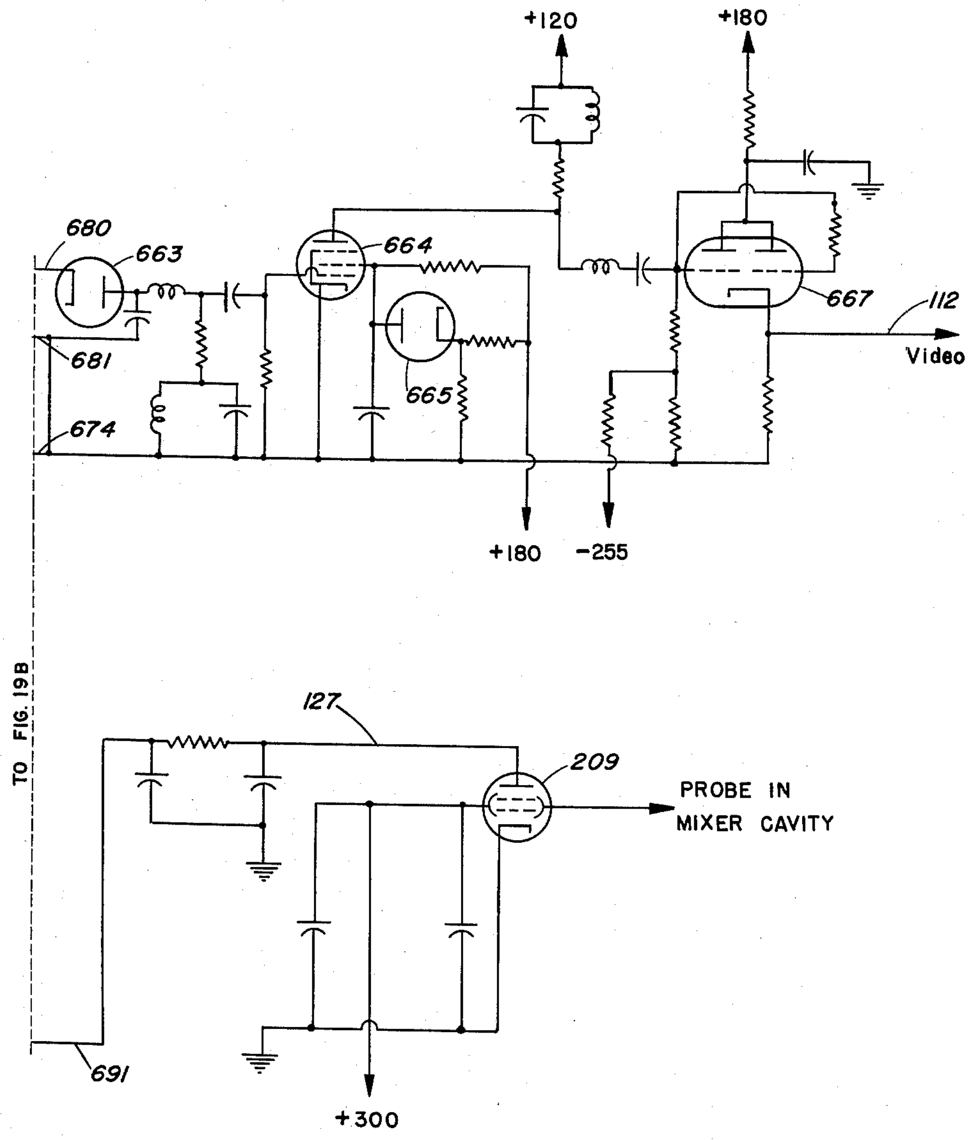
FIG. 19B



RECEIVER CIRCUIT

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

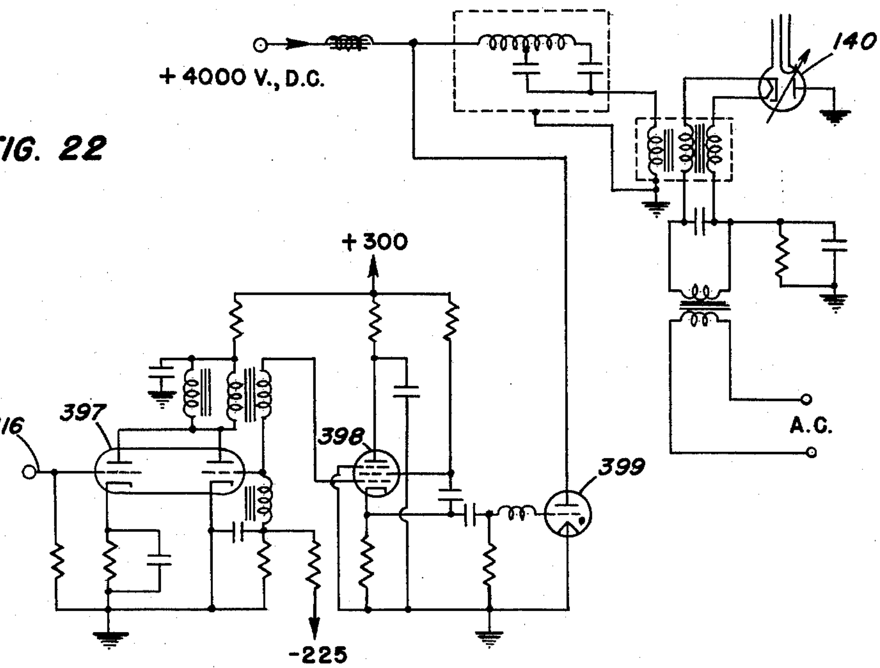
FIG. 19 C



RECEIVER CIRCUIT

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

FIG. 22



MODULATOR AND TRANSMITTER CIRCUIT

INVENTOR
HENRY S. SOMMERS Jr.
BY G. D. O'Brien
ATTORNEY

3,082,415

METHOD AND APPARATUS OF TARGET ACQUISITION

Henry S. Sommers, Jr., New Brunswick, N.J., assignor, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Filed May 2, 1949, Ser. No. 90,802
21 Claims. (Cl. 343—7.4)

This invention relates to a method and apparatus for target acquisition, and more particularly to a method and apparatus utilizing a gun fire control director for selectively or concurrently moving a radar beam in bearing and elevation until the beam is substantially centered on the target and adjusting the radar in range until the target is gated, and thereafter automatically maintaining the radar gated on the target as the target moves in bearing, elevation, and range with respect to the director.

Whereas fire control systems using radar for target acquisition are old in the art, prior art systems have a number of disadvantages. The types of presentation and the coordinates of target motion chosen for use in the radar indicators thereof make the acquisition of the target a slow, complicated, and difficult process.

In the apparatus embodying the instant invention, the types of presentation selected provide for a maximum of target information, and the coordinates selected for the indicators coincide with the coordinates of target motion which are utilized in positioning the director, thereby making the acquisition of the target more rapid and facilitating the task of the operator at the manual controls of the radar and director.

According to a preferred embodiment of apparatus suitable for practicing the method of the invention, a radar antenna rotatable in elevation is mounted upon a director which is itself mounted upon the deck of a vessel and rotatable in train. The antenna comprises a reflector and nutatable antenna adapted to be moved selectively in a manner to produce a conical or spiral scan or pattern of radiation. While utilizing conical scan a radar angle error signal is obtained and utilized to precess a gyroscope in true elevation and true traverse in a manner which tends to maintain the axis of rotation of the gyroscope parallel to a straight line between target and director. The antenna and director are required by servo follow-up to move in response to precessions of the gyroscope in a manner which tends to maintain the axis of radiation of the antenna substantially along the straight line between target and director. A circuit and apparatus are provided for automatically maintaining the target gated in radar range.

While spiral scan is being utilized, a plurality of oscilloscopes provide indications of the deviation of the target from the axis of radiation. Bearing, elevation, and range tachometers and slew levers, conveniently located on a console near the oscilloscopes, provide means for manually shifting the position of the radar beam axis until it is on the target, and adjusting the range gate until the target is gated. Thereupon, by a foot switch or other suitable means, the radiation pattern may be shifted from spiral scan to conical scan and the director made to track the target automatically, while the radar maintains the target automatically gated in range.

The instant invention is particularly well adapted for use aboard a vessel for the reason that roll and pitch do not affect the indications of target position.

The method and apparatus of the instant invention are particularly well adapted for use in the Gun Fire Control System described and claimed in the copending application of Ivan A. Getting for Gun Fire Control Method and System, Serial No. 61,558, filed November 23, 1948.

One of the objects of the instant invention is to provide a new and improved method of target acquisition.

Another object is to provide new and improved target acquisition apparatus.

Another object is to provide new and improved target acquisition apparatus having a director and in which the coordinates utilized in the target position indicators coincide with the coordinates of target motion utilized in positioning the director.

Another object is to provide new and improved target acquisition apparatus which is rapid in operation.

Another object is to provide new and improved target acquisition apparatus in which a minimum number of servo systems are employed.

Still another object is to provide new and improved target acquisition apparatus which may be readily converted by a single manual operation into target tracking apparatus.

Still a further object is to provide new and improved target acquisition apparatus especially suitable for use aboard a vessel and in which movement of the vessel as a result of roll and pitch does not affect the indications of target position.

Other objects and advantages will become apparent after a perusal of the following specification taken in connection with the accompanying drawings in which:

FIGS. 1A and 1B are views in elevation of a suitable director for the gun fire control system employing the instant invention;

FIG. 2 is a cross-sectional view of a suitable nutator and reference generator mechanism suitable for use with the instant invention;

FIG. 3 is a schematic diagram of the interior mechanism of the director of FIGS. 1A and 1B, and the electrical circuits employed in positioning the director and antenna system;

FIGS. 4A, 4B, and 4C are views of the screens of the three radar indicators employed in the instant invention;

FIG. 5 is a view of a suitable console and control arrangement;

FIGS. 6A–6J inclusive taken together comprise a schematic diagram in block form of the radar circuits of the instant invention;

FIGS. 7A and 7B taken together are a schematic diagram of the gyroscope precession circuits of the instant invention;

FIG. 8 is a schematic diagram of the range circuits of the instant invention;

FIGS. 9A, 9B, and 9C are views of the waveforms and time relationships of some of the signals employed in the radar apparatus;

FIG. 10 is a block diagram of the entire radar apparatus;

FIGS. 11A and 11B taken together comprise a schematic circuit diagram of the automatic gain control and angle error detector circuit;

FIGS. 12A and 12B taken together comprise a schematic diagram of the marker circuit;

FIG. 13 is a schematic diagram of a suitable memory circuit for use with the instant invention;

FIGS. 14A and 14B taken together comprise a schematic diagram of the range error detector circuit;

FIGS. 15A and 15B taken together comprise a schematic diagram of the B indicator circuit;

FIGS. 16A and 16B taken together comprise a schematic diagram of the E indicator circuit;

FIGS. 17A and 17B taken together comprise a schematic diagram of the A/R indicator circuit;

FIGS. 18A–18E inclusive taken together comprise a schematic diagram of the synchronizer circuit;

FIGS. 19A to 19C inclusive taken together comprise a schematic diagram of the receiver circuit;

FIG. 20 illustrates the radiation pattern of the radar antenna while in conical scan;

FIG. 21 illustrates the radiation pattern of the radar antenna while in spiral scan; and

FIG. 22 is a schematic diagram of the modulator and transmitter circuit.

Referring now to the drawings in which like reference characters are used throughout to designate like parts, and in particular to FIGS. 1A and 1B thereof, there is shown a director generally designated by the reference numeral **11**. The lower portion of the director designated **16** is fixed to the deck of the vessel, and contains apparatus presently to be described for rotating the upper portion in train about an axis substantially perpendicular to the deck.

Rotatably mounted upon the upper portion of the director is the parabolic reflector **14** of a radar antenna system, having mounting and support mechanism **15** associated therewith; the antenna system is accordingly pivotally mounted upon the director for rotation in elevation. An optical sight generally designated at **13** and a slew sight generally designated at **12** are mounted upon the director for positioning the director and antenna by manual means under the control of an operator stationed in the director and utilizing optical sighting, so that the line of sight of the director or radiation axis of the antenna system is made to substantially coincide with a straight line between target and director, the slew and optical sights being operatively connected by relays and circuit means to train and elevation control circuits hereinafter to be fully described, and shown in FIGS. 7A–B.

In FIG. 1B is shown a front elevational view of the director, with the radar reflector **14** removed.

Particular reference is made now to FIG. 2, in which is shown a suitable scanning and reference generator mechanism contained within a housing **213**, FIG. 3, which is fixed to reflector **14** by member **214**, and which may be contained within or integral with aforementioned member **15**.

A drive motor having a stator **168**, rotor **169**, and field magnet **167** drives a hollow shaft **155** which has an extended flaring shoulder portion **154** in which is mounted a pin **175** which serves as the pivot of a bell crank **174**.

Upon one end of the bell crank **174** is a pin or stud **161** cooperating with a fork end portion **160** of a drive shaft **162**, the other end of shaft **162** having grooves **163** therein for receiving balls **159** which may roll on the interior surface of the antenna drive and support member **158**.

Member **158** is mounted in the parabolic reflector **14** by a pair of gimbal or supporting rings **156** and **157**, ring **156** being movably mounted within a circular aperture **153** within the reflector **14** and pivoted on pins **179** and **180** for rotation about a normally vertical axis, ring **157** being mounted within ring **156** and pivoted for rotation on pins, not shown, about a normally horizontal axis, thus providing for freedom of movement of member **158** with respect to reflector **14**.

The end of member **158** adjacent ring **157** has an inwardly flaring rib to which is secured one portion of an R-F choke joint **178**, to which choke joint portion is fixed the antenna feed **176** and antenna **177**. The other portion of the choke joint **178** has fixed thereto the wave guide **212** for transferring R-F energy to and from the antenna.

Secured to member **155** is a driving pinion **195**, the teeth of which mesh with the teeth of a nutation drive gear **194**, which is secured to one end of and turns shaft **193**. Secured to the other end of shaft **193** is a magnetic clutch member **192**, designed to cooperate with an associated driving disk **191**. A magnet **198**, FIG. 8, is disposed in operative relation to shaft **193** and clutch member **192** and, upon energization from leads **199** and **200**, causes the clutch member to engage the disk.

Disk **191** is attached to a drive shaft **188** which has on the other end thereof the worm **181**. Worm **181** meshes with worm gear **182** which has secured thereon to rotate therewith a driven cam **183**.

A fork **185** is pivoted at **184** and has secured thereto by pin **187** a cam follower **186**, which causes movement of thrust bearing **189** and reciprocating movement of rod **171** as the cam **183** turns.

The other end of rod **171** has a link **172** pivoted thereto, link **172** also being operatively connected at **173** to bell crank **174**. In the operation of the above described scan mechanism, when disk **191** and clutch member **192** are not engaged, antenna feed **176** is rotated in a conical pattern of movement, producing the radiation pattern shown in FIG. 20. When the aforementioned clutch is engaged, the antenna member **176** moves in a spiral pattern, as will readily be understood by those skilled in the art, producing the radiation pattern shown in FIG. 21. Spring **152** causes the follower to be in contact with cam **183** at all times. The magnet **198**, FIG. 8, is energized from battery or source **197** when scan control switches **42** or **43**, FIGS. 5 and 8, are thrown to their "Spiral" or "Search" positions. Means, not shown, is provided for causing the transfer between conical and spiral modes of operation to occur at a predetermined setting of cam **183** and shaft **188**.

By suitable choice of dimensions, a mechanism is preferably provided which in spiral, goes through a spiralling cycle twice per second and has a 12 degree angle of scan in spiral, and a 3 degree angle of scan in conical operation. Preferably the scan rate in conical is 30 times per second, but may be varied in any convenient manner, as by adjusting scan rate control **149**, FIG. 5, any suitable arrangement, not shown, being provided for altering the scan rate.

Operatively connected to the aforementioned drive motor is a reference generator generally designated by the numeral **77**, and having a rotor **164**, a stator **165**, and a field magnet **166**. The reference generator is constructed and arranged to generate two A.-C. reference voltages having the same frequency as the period of conical scan, normally 30 cycles per second, the reference voltages being 90 degrees apart in phase and both having a fixed phase relationship to the rotary position of the antenna feed **176** at any instant, as determined by the mechanical coupling between the antenna and rotor **164**. These reference voltages may accordingly be utilized to resolve a radar angle error signal into two signal components representative of the deviation of the target from the axis of radiation in a pair of mutually perpendicular directions corresponding to true elevation and true traverse, in a manner to be subsequently more fully described.

Reference is made now to FIGS. 6A–6J inclusive which taken together comprise a schematic electrical circuit diagram in block form of the aforementioned radar apparatus **18**, and include a range marker or timer circuit, a synchronizer circuit, a modulator and transmitter circuit, an R-F plumbing circuit, a receiving circuit, a range error detector circuit, and an angle error detector circuit, all of which cooperate to produce the signals which are utilized in positioning the director and antenna system in train and elevation respectively, and gating the target in range. In addition to the aforementioned circuits, three indicator or presentation circuits, for A/R, E, and B types of presentation, are provided for purposes to be more clearly apparent as the description proceeds.

In FIG. 6A is shown the marker circuit which has the function of providing on leads **101** and **102** a pair of sets of fixed 1000 yard reference marks, and on lead **100** a set of shifted 1000 yard reference marks, which may have wave shapes as indicated in FIGS. 9A–9C inclusive. To this end a stable crystal controlled oscillator **2001** is provided, which may comprise the circuit of

electron discharge tube **513** and associated components, FIGS. 12A–B, and which is adapted to generate a substantially sinusoidal voltage of a frequency of 163.880 kc./sec. This frequency is selected because the time interval between successive cycles is that corresponding to the time required for a wave of radiant energy to travel a distance of 2000 yards, or out 1000 yards and return. The output of the oscillator is applied to a phase splitting circuit **2002** which is constructed and arranged to produce three voltages of the same frequency but substantially 120 degrees apart in time and phase. The three voltages are applied to isolating cathode followers **2003**, **2004**, **2005** which may comprise tubes **501** and **502**, whence one of the voltages is applied to a reference sine wave amplifier **2006** which may comprise tubes **503** and **504**, and thence to a reference distortion amplifier **2007** which may comprise tubes **505**, **507**, **509**, and **510** and which supplies the aforementioned fixed marks on leads **101** and **102**. The voltages on the two leads are isolated, as by the use of the cathode followers shown.

All three of the cathode follower outputs of tubes **501** and **502** are applied to a phase shifting circuit **69'**, see FIG. 12A, including range condenser **69**. This phase shifting circuit may comprise in addition to condenser **69** a similar condenser **79**, each of the condensers **69** and **79** including two fixed plates. One plate of each condenser is preferably divided into three equal segments or arcs electrically insulated from each other, each segment being connected to one of the aforementioned cathode followers of tubes **501** and **502**. The other plates of the condensers are connected by way of electron discharge triode tubes **521** and **522** to Useful and Calibration leads **2008**, **2009** respectively from the phase shifting circuit.

In that condenser **69** which is operatively connected to the "Use" terminal, there is located between plates and fixed to the capacitor shaft to rotate therewith, a member composed of dielectric material which may be substantially heart shaped or shaped as the square root of a cardioid. The shaft of this variable capacitor **69** is operatively connected by coupling **70** to a range servo system, FIG. 8, hereinafter to be more fully described, and may rotate through 30 revolutions as the range of the target varies from zero to 30,000 yards. An arrangement is accordingly provided wherein, as the range shaft rotates through 360 degrees, the voltage applied to the control grid of the triode **521** associated with condenser **69** is continuously moved from a time and phase corresponding to one cycle of the voltage on one of the plate segments, to the time and phase corresponding to that of the next cycle of voltage on the same segment.

The dielectric in the other condenser **79** in the phase splitting circuit is not moved, and this condenser and associated triode **522** provide a voltage on the "Cal." lead suitable for calibration purposes.

The useful output of the phase shifting circuit is applied to a shifted sine wave amplifier **2010** which may comprise tubes **514** and **506**, and thence to a shifted distortion amplifier **2011** which may comprise tubes **515**, **508**, **512**, and **511** and which supplies the aforementioned shifted marks on lead **100**. A vacuum tube voltmeter **2012** is preferably provided for adjusting purposes as shown, and may comprise tubes **516**, **517**, and **518**.

Particular reference is made now to FIG. 6C, in which is shown in block form a synchronizer circuit suitable for use with the instant invention. The synchronizer circuit is constructed and arranged to receve the 1000 yard reference marks from lead **101** and the 1000 yard shifted marks from lead **100** and therefrom to generate and provide the following outputs: a modulator trigger for a hereinafter described modulator and applied to lead **116**; and "E" and "A" trigger for hereinafter described E and A/R indicators and AGC and angle error detector, and applied to lead **103**; a screen gate for the gated tube in a hereinafter described range error detector, and applied to lead **104**; a "B and E range mark" for hereinafter described B and E indicators, also used as a clamp gate in a hereinafter described AGC and angle error circuit, and applied to lead **115**; a 0.13 microsecond track gate for use in the range error detector, and applied to lead **105**; an R step trigger for the A/R indicator and applied to lead **117**; an R trigger for the A/R indicator, and applied to lead **118**; and a B trigger for the B indicator, applied to lead **121**. The various blocks of the circuit of FIG. 6C are appropriately labeled. Appropriate shapes for the various trigger outputs of the synchronizer are shown in FIGS. 9A–9C.

A switch **143** is provided for switching from an internal repetition rate oscillator **2013**, which may comprise the circuit of tube **552** and associated components, to an external pulse repetition frequency signal which may be supplied from any convenient source, not shown, on lead **138**. Control **142** is provided for varying the frequency of the internal PRF oscillator **2013**, and is connected in the circuit in the manner shown, FIGS. 18A–E.

The clipper amplifier **2014**, which may comprise the circuit of tube **551** and associated components, is utilized to form a pulse from the repetition rate voltage, which is preferably 3000 c.p.s. This pulse is applied to the amplifier and blocking oscillator circuit $\mathbf{2015_a}$, $\mathbf{2015_b}$, $\mathbf{2015_c}$, $\mathbf{2015_d}$, $\mathbf{2015_e}$ of the tube **554**, the output of which is utilized in coincidence with the fixed 1000 yard reference marks to generate a pulse which starts substantially 1000 yards before the A trigger. Because the repetition rate frequency is different from the frequency of the reference marks, two coincidence stages, comprising tubes **555** and **557**, and **560** and **561** respectively, are employed to provide an A trigger which does not jitter with respect to the other outputs of the synchronizer circuit.

The aforementioned A trigger, after amplification by the buffer amplifier circuit **2016** of tube **553**, is used, as will be subsequently explained more fully, to start the A sweep on the A/R indicator, to start the range sweep on the E indicator, and to provide a sensitivity time control (STC) voltage.

The A trigger occurs in substantial coincidence with one of the reference marks. Two additional coincidence circuits $\mathbf{2015_d}$, $\mathbf{2015_e}$, comprising tubes **563** and **564**, and **569** respectively, are provided to give a 2000 yard delay for the pulse which, after amplification at tube **570** in buffer amplifier **2033** and application to the blocking oscillator circuit **2034** of tube **572**, develops the modulator trigger, the trigger which times the firing of a modulator thyratron hereinafter to be described. It is noted, FIGS. 9A–9C, that the modulator trigger is generated in substantial concidence with the fixed reference mark which is two cycles later in time than the A trigger; accordingly, the modulator trigger is delayed 2000 yards, thereby providing for an arrangement in which the aforementioned A/R and E indicator sweeps will indicate the pulse of transmitted energy. As a result of this arrangement, tracking circuits may be provided which will operate substantially down to zero range.

The coarse delay multivibrator **2017**, which may employ the circuit of tube **556** and associated components, is triggered susbtantially coincident in time with the generation of the A trigger. The coarse delay multivibrator starts or controls the generation of a substantially linear sawtooth voltage as by use of the circuit **2018** of tubes **559**, **558**, and **562**. The pick-off diode tube **565** provides an arrangement whereby when the sawtooth voltage attains an instantaneous amplitude corresponding to the D.-C. voltage level established by the arm of range of potentiometer **68**, which is coupled by coupling **70** to a range servo motor hereinafter to be described, a pip selector gate is generated. A change in the range setting of the range servo motor changes the D.-C. voltage level and accordingly produces a corresponding change in the

time interval between the A trigger and the pip selector gate.

The pip selector gate is applied to an amplifier **2021** which may comprise tube **566** and thence to a coarse delay trigger amplifier and blocking oscillator **2022** which may comprise tube **567**, which provides a screen gate, and also an output voltage for application by way of the buffer stage **2023** of tube **571** to the first delayed coincidence amplifier and blocking oscillator **2024** of the demodulator section of the synchronizer circuit, which also has applied thereto the shifted 1000 yard marks, and which may comprise the circuit of tubes **574** and **576**. This arrangement, in which the pip selector gate (which is a coarse measure of range) and the 1000 yard shifted marks are applied to a coincidence circuit, provides for highly accurate timing of several subsequently generated signals. One of these is the B trigger, amplified as shown by tube **577** in block **2028** and utilized to initiate the 2000 yard range sweep of the B indicator.

The coarse delay trigger and blocking oscillator circuit **2022** of tube **567** also supplies an input to the multivibrator stop trigger amplifier **2020**, which may comprise tube **568** and which delivers its output to the coarse delay multivibrator **2027**.

The R trigger blocking oscillator and buffer amplifier circuit **2028** of tubes **573** and **575** is provided as shown, energized from the B trigger amplifier **2027**, for the generation of an R trigger substantially 500 yards after the B trigger, the R trigger being utilized for initiating the 1000 yard R sweep on the A/R indicator.

Operatively connected to the circuit which generates the B trigger is a second coincidence circuit **2025**, which may comprise tube **578**, and which has applied thereto a movable reference mark which is delayed 1000 yards from the B trigger. From this second coincidence circuit by way of a buffer amplifier tube **580** there is developed in the blocking oscillator circuit **2029** of tube **582** an R step trigger, which is amplified as shown by tube **579** in block **2026** and utilized to produce the step in the middle of the R sweep of the A/R indicator.

Concurrently with the generation of the R step trigger, a range mark is generated, the range mark being utilized in the E and B indicators, and also serving as an automatic gain control (AGC) gate trigger, for purposes to be hereinafter described.

The output of the R step trigger blocking oscillator **2029** is applied by way of a delay line **2031** to a track gate trigger amplifier and blocking oscillator **2032** which may comprise tubes **583** and **581**, in which is generated a 0.13 microsecond track gate for application to a range error detector hereinafter to be described.

Particular reference is made now to FIG. 6D, in which is shown in block diagram a suitable modulator and transmitter circuit. The radar modulator, transmitter, and receiver may conveniently be located in compartment **20** of the director, FIG. 1B, with the power supplies therefor in compartment **19**, and may be operatively connected by the R-F plumbing of FIG. 6J to the antenna system. The aforementioned modulator trigger is applied by way of lead **116** to a trigger amplifier tube **397** in block **2035**, by way of a cathode follower tube **398** in block **2036** to a thyratron modulator tube **399** in block **2037**. The anode of the thyratron is connected by way of a charging inductance **2028** to a source of modulator power, not shown, which may be of the order of +4000 v., D.-C., with respect to ground. The anode of the thyratron is further connected by way of a pulse network **2039** and pulse transformer **2040** to a magnetron **140** in block **2041**, which is operatively connected to R-F plumbing subsequently to be described. It is understood that suitable component values are selected to provide a pulse of the desired width, preferably 0.1 microsecond, and preferably having a steep wave front.

Particular reference is made now to FIG. 6J, in which is shown the R.-F. plumbing circuit. Flexible coupling **201** connects to the aforementioned magnetron **140**. A pair of ATR tubes **202** and **203** are preferably located in the position shown. A TR tube **215** is provided, as shown. Preferably, a negative keep-alive voltage is applied to the TR tube by way of lead **135** from a suitable source of potential, not shown. Four crystals **204**, **205**, **206**, and **207** are utilized, two for the signal section of the receiver generally designated at **208**, and two for the automatic frequency control channel of the receiver hereinafter to be more fully described. A local oscillator is provided at **209** contained within a suitable housing, and having lead **127** connected thereto for purposes to be hereinafter apparent. A second flexible coupling is provided at **219**, whence a wave guide arrangement generally designated **260** is provided including R.-F. stabilizer **216**, choke vertabrae sections **217**, and oscillating joint **218**, an additional choke vertabrae section **220**, wave guide portion **212**, R.-F. choke joint **178**, antenna feed **176**, and antenna **177**.

Particular reference is made now to FIGS. 6E and 19A–19C in which are shown a suitable receiver circuit for use with the instant invention. In the signal channel (the upper channel FIG. 6E), the inputs from two of the aforementioned crystals located in the R.-F. plumbing are applied to an input coupling net **2042**, the output of which is applied to a low noise I-F input circuit **2043** which may comprise tubes **651** and **652**, and thence by way of leads **671**, **672**, **673**, **674**, and **675** to an I-F amplifier **2044** which may conveniently contain ten stages of amplification which may be similar to the stage of tubes **656** and **659**. A slow automatic gain control signal, obtained from an AGC and angle error circuit presently to be described, is applied by way of lead **114** to two of the earlier stages of I-F amplification, preferably the first and fifth stages, as shown. A fast automatic gain and sensitivity time control signal obtained from the aforementioned AGC and angle error circuit is applied by way of lead **113** preferably to the seventh and tenth amplifier stages. The output of the I-F amplifier is applied by way of leads **680**, **681**, and **674** to a second detector **2045** which may comprise tube **663**, thence to a video amplifier and limiter **2046** which may comprise tubes **664** and **665** and thence to a cathode follower tube **667** in block **2047** which supplies the useful video signal to lead **112**, the video signal which is used in all indicators and the range error circuit. This signal may be conveniently of an amplitude of 1.5 volts. The automatic gain control signals and sensitivity time control signals are provided to assist in maintaining substantially constant output, as the target varies in range or in aspect. It is understood that manual gain is also provided, preferably connected as shown in FIG. 6I and adjustable from the console, as by control **144**, FIG. 5. A switch **146** is provided for switching the receiver from automatic to manual gain control; it is understood that control **144** is effective only when switch **146** is on its "Manual" setting. Preferably the manual gain control is not utilized when the system is tracking a target automatically in conical scan. A switch **148** is provided in the AGC and angle error circuit presently to be described for switching the sensitivity time control signal selectively into and out of the receiver circuit, as desired.

In the automatic frequency control section or channel of the receiver circuit, FIG. 6E, the outputs from the two aforementioned AFC crystals are applied to input coupling networks **2048**, thence to an amplifier **2049** comprising tubes **653** and **655**, thence by way of lead **676**, **677**, **678**, and **679** to a discriminator **2050** comprising tubes **657** and **658**, thence to AFC video amplifier tube **660** in block **2051**, and trigger thyratron tube **661** in block **2052**, in the order named, to the sweep generating thyratron tube **662** in block **2053** which by way of leads **691** and **127** controls the anode voltage on the tube of local oscillator **209** and accordingly controls the frequency of the oscillator. When tuning control switch **147′** is in the

AFC position, the control voltage from the thyratron sweep generator is applied to the tube by way of lead **127**. When switch **147'** is on its "Manual" setting shown in FIG. 6E, a manual control **145'**, which may be of conventional design, controls the frequency of local oscillator **209**. Switch **147** and control **145** of FIG. 19B may conveniently be mounted upon the console, FIG. 5. The reference numerals **147'** and **145'** are employed in the block diagram to designate simplified elements corresponding to those of the circuit of FIG. 19B.

As aforementioned, the radar modulator, transmitter, and receiver are preferably located in the director in compartment **20**, whereas the radar target position indicators, marker and synchronizer circuits, angle and range error detectors, and switches and controls therefor are preferably located below deck in and upon a suitable console. Preferably the director and below deck components are operatively connected through a slip ring assembly mounted in the director and characterized by low leakage and low capacity between the individual rings and circuits thereof, and uniform contact resistance. A slip ring assembly especially suitable for the purpose is described and claimed in the copending application of Elmer J. Scott for Slip Ring Assembly, Serial No. 65,497, filed December 15, 1948, now Patent No. 2,725,540 issued November 29, 1955.

Particular reference is made now to FIG. 6B, in which is shown in block form a range error detector circuit suitable for use in the instant invention, and to FIGS. 14A and 14B in which is shown a schematic circuit diagram thereof. The circuit receives as inputs a screen gate on lead **104**, the aforementioned 0.13 microsecond track gate on lead **105**, and the video signal on lead **112**, which is applied to a video amplifier **2054**. A switch **100A** is provided as shown, for selectively applying the 1000 yard shifted marks on lead **100** to the video amplifier for calibration purposes. The various elements contained in the various blocks are appropriately labeled.

The video input signal is amplified, preferably by an amplifier compensated for high frequency response. The circuit of electron discharge tubes **485** and **484** and associated components is suitable for the purpose. The output of the amplifier is coupled to a D.-C. restorer **2055**, which may comprise the circuit of electron discharge tube **477** and associated components, and thence to two gated video amplifier stages **2056** and **2057** comprising pentodes **478** and **479** and associated components. The D.-C. restorer is provided to prevent the development of a negative grid bias on a grid coupling resistor which may be common to the two gated video stages, as shown. In these two later stages the two similar pentodes have the screen gate signal applied by way of a buffer amplifier **2058**, comprising tube **476** and associated components, in phase on the two screen grids, the video signal applied in phase on the two control grids, and the late and early tracking gates, obtained from the 0.13 microsecond tracking gate, applied to the respective suppressor grids. It is noted that the delay time of the delayed gate **2059** corresponds to the width of the transmitted pulse.

The screen gate may preferably be 6 microseconds' wide and substantially centered on the tracking gate, as shown in FIG. 9C. By suitable choice of operating potentials and component values, an arrangement is provided whereby when both screen and tracking gates appear in the absence of a video signal on the control grids, a nearly square pedestal pulse is produced in each gated video circuit. A signal applied to the control grids causes an addition to this pedestal. The net pulse amplitude after removal of a portion of the square component represents the gated video signal.

The outputs from the late and early gated video amplifiers are applied to late and early peak diode detectors **2060** and **2061** respectively, which may comprise the circuits of tubes **480** and **481** respectively and associated components, where capacitances are charged substantially to the peak value of the net pulse. The pedestal portion of the pulse may be removed by biasing the cathodes of the diode detector tubes positive with respect to their plates, as shown. Preferably this bias may be adjusted in value, and preferably only a portion, for example, 9/10, of the pedestal is removed, to obviate the possibility of cutting of a portion of the gated video signal. Preferably means, as shown, is provided for equalizing the amplitudes of the pedestals so that the outputs of the peak detectors will be substantially equal in the absence of a video signal input to the range error detector.

The outputs of the diode peak detectors or inputs to the following amplifier stages may comprise signals having a wave shape corresponding to the stretched video signal, FIG. 9C, and having a peak value equal in amplitude to the gated video signal plus a relatively small portion of the pedestal pulse. These are applied to the amplifier and cathode follower stages **2062** and **2063** shown, comprising tubes **482**, **483**, **486**, and **487** and associated components, the outputs of which provide the late and early gates on leads **107** and **106** for an angle error detector presently to be described. The outputs of the cathode followers are further applied by way of the transformers **2064** and **2065** shown to a third detector circuit **2066** comprising a pair of diode demodulators **488** and associated components, and constructed and arranged to provide an error voltage having an amplitude proportional to the difference in amplitudes of the early and late gated video signals, and a polarity depending upon which signal is greater. This error signal is applied to a range servo circuit, FIG. 8, to be subsequently explained in detail, and the polarity of the error voltage is always such as to cause the range servo motor to turn in a predetermined direction, and hence the phase shifting capacitor **69**, FIG. 6A, and the range potentiometer **68**, FIG. 6C, to move the tracking gate on lead **105** in a direction so that the signal tracked is centered between the early and late video gates. Under such a condition, the range error signal is substantially zero.

Particular reference is made now to FIG. 6I, in which is shown in block form the aforementioned AGC and angle error circuit, and to FIGS. 11A and 11B in which is shown a schematic circuit diagram. Inputs include the "E" and "B" range marks on lead **115**, the early and late gates on leads **106** and **107**, and the A trigger on lead **103**. The various parts of the circuit indicated in the blocks are appropriately labeled.

The AGC and angle error circuit has several functions: one is to maintain the signal in the receiver at a substantially constant amplitude; another is to supply gyroscope precession circuits hereinafter to be described with a 30 cycle angle error signal; and a third function is to provide for an aforedescribed arrangement in which receiver gain varies with time, so that a moving target is viewed by the radar director at substantially constant amplitude independently of changes in range.

To this end, an adding network **2067** is provided in which the early gated video signal on lead **106** and the late gated video signal on lead **107** are added, providing a pulse which is amplified, as by the amplifier circuit **2068** of tube **301**, applied to a fast acting cathode follower **2069** which may comprise the circuit of tube **302** and associated components, and thence applied to a clamp gate detector circuit **2071**, which may comprise the circuit of tube **303**, capacitor **320**, and associated components. This detector tube **303** is turned on by a clamp gate, which is generated in a clamp gate blocking oscillator **2072** which may comprise the circuit of tube **310** and associated components, and applied by way of the transformer having windings **316**, **317**, **318**, and **319**. The operation of the clamp gate blocking oscillator is controlled by a trigger from the amplifier tube **309**, in block **2073** to which the E and B range marks on lead **115** are applied by way of a suitable delay line **2074**.

The output of the circuit of detector tube **303** is ap-

plied to a buffer cathode follower **2075** which may comprise the circuit of tube **304**, and thence, when switch **146** is in the "Automatic" position shown in FIG. 6I, to a limiter circuit **2076** which may comprise tube **305** and associated components.

Whereas, for convenience of illustration, switch **146** is shown in FIG. 6I as a single-pole double-through switch, preferably switch **146** is manually controlled relay as shown in FIG. 11B.

The output of limiter tube **305** is applied to a cathode follower **2077**, tube **307**, whence a 30 cycle angle error signal on lead **130** and a fast AGC signal on lead **133** are taken.

The aforedescribed circuit provides an arrangement in which the amplitudes of the fast AGC signal and angle error signal are adjusted by each gated video pulse substantially in accordance with the amplitude of each video signal. For large or close targets, a relatively large negative D.-C. voltage is developed by the aforementioned detector which is applied to the I-F amplifiers of the aforementioned receiver and reduces the gain thereof. Also, as the antenna feed rotates, the video signal selectively increases and decreases through each cycle of rotation if the target is not substantially in the center of the cone described by the rotation of the aforementioned antenna feed.

Another output from the fast AGC and angle error cathode follower tube **307** is applied by way of limiter **2078**, tube **306**, to a slow AGC cathode follower **2079**, which may comprise the circuit of tube **308** and associated components, from which a slow AGC signal is obtained on lead **114** and applied to the radar receiver in a manner previously described.

An aforementioned A trigger on lead **103** is applied, when the switch **148** shown is closed, to a Sensitivity Time Control Amplifier **2081** which may comprise the circuit of tube **311** and associated components. The output of tube **311** is applied to a cathode follower **2082**, which may comprise the circuit of tube **312**, whence an output is applied to the aforementioned slow AGC cathode follower **2079** circuit of tube **308**. This arrangement is provided because it is usually desirable to cause the video signal in the receiver to appear at a level substantially independent of range, and when switch **148** is closed, lead **114** also has applied thereto a sensitivity time control signal.

When switch **146** is on its Manual Setting, the manual gain control **144** may be utilized to control the gain of the receiver.

The angle error signal is developed on lead **130**. The instant magnitude of this signal represents the amount of the instantaneous deviation of the target from the line of sight or radiation axis of the aforementioned antenna system. The aforementioned fact AGC output signal is developed on lead **113**, and the aforementioned slow AGC output signal on lead **114**.

Particular reference is made now to FIG. 3 and to FIG. 7B for an understanding of the manner in which the aforementioned angle error signal, in conjunction with the aforementioned reference signals or voltages from generator **77**, is utilized to maintain the line of sight of the director substantially on the target.

The rotatable member of the director, indicated in FIG. 3 by the reference numeral **253**, is adapted to rotate or pivot through an angle of 360 degrees around an axis vertical to the deck of the vessel, and has gear teeth meshing with the teeth of a driving gear **254**, which is driven by shaft **255** by means hereinafter to be more fully described, to position the gear or base **253** in train. It is understood that the rotation of gear **253** rotates the entire upper portion of the director, FIG. 1A. Fixedly mounted upon member **253** are a pair of spaced upright supports **251** and **252** which have bearing journals **246** and **247** respectively mounted therein for receiving bearing shafts **244** and **245**.

Fixed to shafts **244** and **245** to rotate therewith, is a rectangular frame member **261**, which is pivotally mounted to permit rotation about the axis of shafts **244** and **245**. Mounted within member **261** is a second somewhat smaller rectangular frame member **262** adapted to rotate about an axis perpendicular to the axis of shafts **244** and **245**, the bearing pin **286** being provided for this purpose, and gear **241** being fixed to rotate with frame member **262** and adapted to freely rotate about a suitable pin or other mounting member (not shown) mounted in frame member **261**. Gear **238**, driven from shaft **237**, meshes with gear **241** and positions the frame member **262** by the quantity *Zs*, in a manner to be subsequently more fully described.

Mounted within the frame member **262** are: the aforementioned vertical and line-of-sight gyroscopes, the vertical gyroscope comprising rotor **267** which may rotate upon shaft **271**; inner gimbal ring **266** which may rotate with shaft **272** and having a pick-off transformer generally designated by the reference numeral **263** for obtaining a voltage proportional to the quantity *eZs* or error in cross traverse, in a manner to be subsequently more fully described; and, outer gimbal ring **265** which may be mounted to rotate with a shaft **268** pivoted for rotation in frame member **262**, which shaft **268** has thereon a pickoff transformer **264** for obtaining a voltage representative of the quantity E or true elevation. The operation of the pick-off transformers **263** and **264** is conventional and need not be described in detail.

In the operation of the vertical gyroscope, the rotor **267** may be driven by any suitable means, not shown, for example, a synchronous motor energized from a power supply of stable amplitude and which has its frequency stabilized, as by a 400 cycle tuning fork.

The rotation of the rotor **267** maintains the shaft **271** in a true vertical position as the director trains and elevates, while outer gimbal ring **265** has the axis of rotation thereof determined by the position of the inner rectangular frame member **262**. As a result, transformer **264** supplies a voltage substantially proportional to the quantity E and, since frame **262** is rotated by the quantity *Zs*, transformer **263** provides a voltage substantially proportional to the quantity *eZs*, these voltages being utilized for purposes to be hereinafter apparent. If desired, a sec. E attenuator, not shown, may be interposed between the transformer **263** and *Zs* servo motor **295**.

A second gyroscope, the aforementioned line-of-sight gyroscope, comprises a gyro rotor **275** which is rotated at constant speed by any convenient means, not shown. The rotation of the rotor **275** may take place about a shaft **279** supported in inner gimbal ring **277**. The inner gimbal ring **277** may be fixed to a shaft **280** for rotation therewith within the outer gimbal ring **276**. Fixed to shaft **280** is a torque motor coil generally designated by the reference numeral **82**, for purposes to be hereinafter apparent. Fixed to shaft **278**, which may be fixed to ring **276**, is a second torque motor coil generally designated by the reference numeral **81**, these torque motor coils being portions of torque motor which, when energized by currents from leads **225** and **226**, precess the line-of-sight gyroscope in traverse and elevation.

The coils **81** and **82** have associated therewith respectively cores of permanently magnetic material, not shown. The cores may be mounted upon a housing, not shown, for the line-of-sight gyroscope, which may be connected to frame **262**. Whereas the line-of-sight gyroscope, for convenience of illustration, is shown as "floating," that is, unsupported, it is understood that suitable supporting means is provided for mounting this gyroscope within frame **262** in a manner to allow freedom for precessive movements thereof.

Attached to the rectangular frame member **262** is a cross support **269** on which are mounted the primary and secondaries of a double E transformer **273** of conventional design. A reluctance dome **290** is attached to shaft **274**,

which is attached to gimbal **277** and moves with movements of the axis of rotation of rotor **275**, and provides for the generation of two voltages in the secondaries of the double E transformer proportional to the displacement of the dome from its center position in two mutually perpendicular directions. These voltages are representative of the quantities *e*E and *e*B*s*, which may be defined as substantially the errors by which the line of sight of the director departs from the straight line between target and director in true elevation and true traverse respectively, and are applied by way of leads **299** and **300** respectively to a resolver **293**, where they are resolved by the quantity Z*s* and converted from true to deck coordinates.

The aforementioned trunnions **251** and **252** have extended arm portions **249** and **250** respectively. A shaft **231** is supported in bearings in arms **249** and **250** and has fixed thereto for rotation therewith a gear **232**, the teeth of which gear mesh with the teeth of a gear **235** fixed to shaft **236**, while the shaft **236** is connected to servo motor or servo system **297** and positions shaft **231** by the quantity E′*b*. Shaft **231** may have fixed thereto to rotate therewith the aforementioned housing **213** for the aforedescribed scanning mechanism, and which is operatively connected by means of the aforementioned member **214** with the aforedescribed antenna reflector **14**. The scanning mechanism, reflector, and antenna system associated therewith provide means, when conical scan is employed, for causing a recurrent series of overlapping conical patterns of radiation of a type to permit a range error and angle error signals to be produced by the radar apparatus, as afore-explained.

Gear **232** has a pin **233** fixed thereon, and frame **261** has a raised arm portion **243** having pin **242** fixed thereon. Pins **233** and **242** are operatively connected by link **234** for positioning frame member **261** by the quantity E′*b*.

The aforementioned voltages from the aforementioned double E transformer **273** are applied by way of leads **299** and **300** to an aforementioned resolver **293**, where, as previously explained, they are resolved by the quantity Z*s* to convert from true to deck coordinates. After resolution, one of the aforementioned voltages is applied by way of amplifier and amplidyne **296** to an E′*b* drive motor **297** which positions the aforementioned shaft **231** and antenna system by E′*b*, and also the frame member **261**.

The other output voltage from resolver **293** is applied by way of amplifier **258** and amplidyne **257** to B′*r*′ drive motor **256**, which drives gear **254** by mechanical coupling **255**, thereby positioning the director in train.

The aforementioned *e*Z*s* pick-off transformer **263** is connected to Z*s* servo motor **295**, which is connected to aforementioned Z*s* resolvers **293** and **76**, and to aforementioned shaft **237**.

If desired a secant E′*b* attenuator, not shown, may be interposed between the resolver **293** and amplifier **258**.

The aforementioned reference voltages from the reference generator **77**, FIG. 7B, also FIG. 2, are applied by way of leads **95** and **96** to a resolver **76** which may also be of conventional design. Resolver **76**, as shown in FIG. 3, has the moving element thereof positioned by the quantity Z*s* by suitable mechanical coupling to the Z*s* servo motor **295** operatively connected to the aforementioned *e*Z*s* pick-off transformer **263**, and converts the reference voltages from deck to true or stabilized coordinates.

Particular reference is made now to FIGS. 7A–B for an understanding of the apparatus which employs the aforementioned radar angle error signal and the aforementioned resolved reference voltages to precess the line-of-sight gyroscope in traverse and elevation. The two voltage outputs of resolver **76** are applied by way of leads **93** and **94**, FIG. 7B, to a pair of similar filters **73** and **75** which may be of conventional design. The outputs of these filters are applied by way of the contacts of relays **57** and **58** respectively to a pair of similar phase discriminators **83** and **84** respectively.

The angle error signal on lead **130** is applied to a filter **74**, which is preferably substantially identical with filters **73** and **75**. This is desirable so that substantially equal phase shifts will take place in the error signal and reference voltages.

The output of error signal filter **74** is applied to one contact of a relay **78** which has the energization thereof controlled by way of leads **37** and **38** from scan control switches and energizing source **42** and **43**. The relay **78** is constructed and arranged, when the scan control switches are in "Spiral" or "Search" positions, to disconnect the error signal or output of filter **74** from the following portions of the circuit.

When the scan control switches are in "Conical" or "Automatic tracking" position, the output of filter **74** is applied by way of relay **78** to a second relay **56**. Relay **56** is constructed and arranged when energized by way of lead **72** from source **59** upon the closing of switch **71** to connect the filtered error signal from filter **74** to both leads **87** and **88** and accordingly supply the filtered radar error signal to both the phase discriminators **83** and **84**. The phase discriminators **83** and **84** may be of conventional design, and are constructed and arranged to utilize the reference voltages to derive from the angle error signal two component signals representative of the elevation and traverse errors, as will be readily understood by those skilled in the art.

Relay **56** when de-energized interrupts the signal from **74** and applies optically controlled signals, obtained in a manner to be hereinafter described, on leads **53** and **54**, to leads **87** and **88** respectively.

Relays **57** and **58** are also energized by way of lead **72** from source **59** substantially simultaneously with the energization of relay **56**, and are de-energized in synchronism therewith. When energized, relays **57** and **58** connect the outputs of filters **73** and **75** into phase discriminators **83** and **84** respectively. When de-energized, relays **57** and **58** interrupt the signals of filters **73** and **75**, and apply to both the phase discriminators **83** and **84** voltages of 110 v., A.-C., 60 cycles, one side of the 60 cycle A.-C. voltage being grounded in each case.

In FIG. 7A is shown the circuit for obtaining the aforementioned signals or voltages on leads **53** and **54**, FIG. 7*B*. Operatively connected with the aforementioned slew sight **12**, FIGS. 1A–1B, are a pair of control transformers **351** and **352** which have their control elements positioned by suitable mechanical couplings in train and elevation respectively in accordance with movements of the slew sight. The control transformers **351** and **352** may conveniently by energized from a source of potential, not shown, of 110 v., A.-C., 60 cycles. The output of the transformer **351** is applied to a secant attenuator **360** which has the moving element thereof positioned by the quantity E′*b* by suitable coupling to an aforementioned E′*b* drive motor **297**, and thence is applied, together with the output of control transformer **352**, to the primaries of a resolver **359** which has applied thereto a shaft rotation corresponding to the quantity Z*s* and obtained from Z*s* servo motor **295**. The outputs of the resolver **359** are applied to contacts of a relay **357**, which is arranged to be selectively energized and de-energized by the operation of switch **358**, battery **361** being provided for this purpose.

Operatively associated with aforementioned optical sight **13** are a pair of control transformers **353** and **354**, energized from a source of potential, not shown, of the order of 110 v., A.-C., 60 cycles. The control element of **353** is positioned in accordance with movements of the optical sight in train, while the control element of transformer **354** is positioned in accordance with movements of the optical sight in elevation. The outputs of transformers **353** and **354** are applied by way of leads **355** and

356 to relay 357. Relay 357 may be constructed and arranged, when energized, to connect the outputs of resolver 359 to leads 54 and 53, and when de-energized to connect leads 355 and 356 to leads 54 and 53 respectively. Switch 358, the setting of which determines which of the outputs of the slew or optical sights are applied to relay 56, may conveniently be located on the gun director of FIGS. 1A–1B.

The output of phase discriminator 83 is applied to an elevation network 85, which includes an elevation slew signal generator, which may be of conventional design, and which is controlled from slew lever 46, and an elevation tachometer signal generator, which may be of conventional design and which is controlled from tachometer handknob 47. Relays may be provided associated with the slew and tachometer elevation signal generators for selectively connecting them into the circuit when their controls are operated, and disconnecting them when they are not operated. These manually controlled elevation signal generators are provided, as will be hereinafter more clearly apparent, for permitting the operator to position the antenna system in elevation in accordance with indications of the position of the target, as shown on a plurality of radar indicators presently to be more fully described.

The output of network 85 is applied to an amplifier 91 which may be of conventional design, and the output of the amplifier is applied by way of lead 226 to the elevation torque motor coil 81 and energizes the latter, causing the line-of-sight gyroscope to precess in elevation in a direction controlled by the polarity of the signal applied to the torque motor, and at a rate controlled by the magnitude of the signal.

The gyroscope, which by its very nature cannot precess rapidly, smooths fluctuations in the elevation signal, in a statistical sense, so that the rate of gyroscope precession is an accurate measure of the rate of target motion.

The output of phase discriminator 84 is applied to a bearing or traverse network 90, which may be somewhat similar to network 85, and which includes slew and tachometer signal generators controlled by members 51 and 52 respectively. The output of network 90, after amplification at 92, is applied by way of lead 225 to traverse torque motor coil 82, and energizes the torque motor thereby to precess the line-of-sight gyroscope in traverse.

The filters, phase discriminators, networks, and amplifiers of FIG. 7B are all included in the apparatus shown in block form at 99, FIG. 3.

Reference is made now to FIG. 6F, in which is shown in block form a schematic circuit diagram suitable for use in the aforementioned A/R indicator, and for providing a pattern of indication corresponding to that shown in FIG. 4C. The lower trace, FIG. 4C, is the A trace, and the length thereof corresponds to a distance of 30,000 yards, or the maximum range of the radar. Markers on the screen are supplied as shown at 10,000 and 20,000 yards. The pedestal of the A trace is of a width corresponding to 1000 yards, or the entire length of the R trace. The pedestal of the A trace moves with movement of the range gate, and an arrangement is provided whereby the left end of the A pedestal coincides with the step on the R trace, next to be described.

The R trace represents a distance of 1000 yards, and the R step thereof is fixed at the half way or 500 yard mark. When a target is properly gated in range, it appears at the foot of the R step, as shown. The other and larger ungated target is also shown for convenience of illustration. When the system is tracking automatically, the gated moving target remains substantially stationary at the base of the R step, while the range mark, or slight break in the trace, moves to left or right selectively in accordance with increasing or decreasing range of the target. In the process of gating the target in range, with the radar in spiral scan, the range gate is moved until the desired target is observed at the foot of the R step, when the radar is shifted to conical scan and continues to track the target automatically.

In FIG. 6F, the circuit for providing the desired indication of FIG. 4C is shown in block form, and in FIGS. 17A and 17B is shown schematically. It is noted that the circuit employs the following inputs; the R trigger on lead 118, the A trigger on lead 103, the R step trigger on lead 117, the 1000 yard reference marks on lead 102, and the video signal on lead 112.

The individual circuits of the blocks of FIG. 6F are constructed and arranged to provided for operation as follows: The A and R triggers from leads 103 and 118 respectively are applied to A and R coincidence circuits 2083 comprising, electron discharge tubes 413 and 414 respectively and associated components. The A trigger coincidence circuit of tube 413 selects alternate A triggers and the R trigger coincidence circuit of tube 414 selects alternate R triggers.

The outputs of the coincidence circuits 2083 are applied to a sweep gate multivibrator and intensifier circuit 2084 comprising, electron discharge tubes 402, 403, and 404 and associated components, and the output of the sweep gate multivibrator is utilized to form an electronic switch trigger 2085, which, after amplification as shown, by the circuit of tube 401 and associated components, is applied to an electronic switch circuit, 2086, which may comprise tubes 411 and 412 and associated components and which generates A and R gates which are applied to the A and R coincidence circuits respectively, thereby forming a closed loop, and providing for the aforementioned selection of alternate triggers by the coincidence circuits. The electronic switch circuit also provides a variable amplitude R gate (R step) for application to a trace separation circuit 2087, which may comprise electron discharge tubes 424, 425, and 426 and associated components. As will be apparent from a consideration of the circuit, the A gate is also applied to a dynamic focus intensity circuit, 2088, which may comprise tube 418 and associated components, and which changes the focus and intensity of the trace on the cathode ray indicator tube.

The aforementioned sweep gate multivibrator 2084 also gates the sweep generator and sweep speed switching circuit 2089, which may comprise the circuit of electron discharge tubes 433, 407, 406, 417, and 419 and associated components, and supplies a gate to the intensifier circuits. It is the function of the intensifier circuit to intensify both the A and R sweeps, and also supply a blanking pulse to the cathode ray tube.

The aforementioned sweep generator provides a push-pull, D.-C. restored sweep which is applied by way of a phase inverter and D.-C. restorers 2091, which may comprise electron discharge tubes 408 and 409 and associated components, to the horizontal deflection plates of the cathode ray tube. The sweep length compensator circuit 2092 of tube 410 is also provided, connected as shown.

The sweep speed switching circuit 2089 changes the sweep speed from that corresponding to the 1000 yard R sweep to that corresponding to the 30,000 yard A sweep, on alternate sweeps. The sweep length trigger circuit 2093 of tube 405 controls the length of the A and R sweeps.

The step multivibrator 2094, which may comprise the circuit of electron discharge tubes 422 and 423 and associated components, is triggered by the negative R step trigger on lead 117, provides the R step and A notch, and delivers its output to the aforementioned step amplitude and trace separation circuits 2087, which have the aforementioned R gate and variable R gate applied thereto, and which by way of the centering circuit 2095 of tube 420 varies the potential between the vertical deflection plates of the cathode ray tube to give vertical deflections of the R step, provide the notch on the A sweep, and provide separation between the R sweep and the A sweep.

The range mark circuit 2096, which may comprise the

circuit of tubes **415** and **416** and associated components, sharpens the positive 1000 yard reference marks obtained from the marker circuits by way of lead **102** before application to the R sweep as 1000 yard range markers, by way of the D.-C. restorer tube **432**.

The video signal on lead **112** is amplified as shown by a circuit **2097**, which may comprise electron discharge tubes **427**, **428**, **429**, **430**, and **431** and associated components, and applied by way of the aforementioned centering and D.-C. restorer circuit **2095** to the vertical deflecting plate of the cathode ray tube **421**.

Particular reference is made now to FIG. 6H, in which is shown in block form a diagram of a circuit suitable for use in the aforementioned E indicator **24**, to FIG. 4B, in which is shown a typical E presentation on the E indicator screen **25**, and to FIGS. 16A and 16B, in which is shown a schematic E indicator circuit diagram. It is noted that the E indicator of FIG. 4B provides for an indication of elevation plotted against range along the other coordinate. The elevation coordinate may selectively show true or expanded elevation, switch **141** being provided for switching between these two conditions of operation, the drawing of FIG. 4B showing a typical pattern when the switch is in its "True" or "Normal" setting and the radar is in spiral scan. The spiraling of the antenna causes a shaded area on the oscilloscope, of a width corresponding to the angular coverage of the spiraling beam, shown in the lower portion of FIG. 4B and designated Spiral Scan Coverage. The main axis of the antenna system is elevated in an amount which corresponds to the center elevation of the spiral scan coverage area, the spiral scan covering an area of substantially 6 degrees on each side of the radiation axis. In acquiring a target the range gate is moved in a manner subsequently to be described until it occupies a position substantially on the desired target.

When switch **141** is in its "Expanded" setting, the axis of radiation of the antenna moves to the horizontal center of the indicator, and the spiral scanning area is expanded to cover substantially the entire indicator screen.

Preferably the E indicator has included therein a true bearing indicator **32**, FIG. 5, which indicates true bearing and is energized by a signal obtained from any convenient source.

In FIG. 6H is shown a circuit suitable for use with the E indicator. The various elements of the circuit are appropriately labelled in the blocks. A potentiometer or other suitable device **285** operatively connected to elevation servo motor **289** controlled from aforementioned E pick-off transformer **264**, provides a signal for application to lead **128** corresponding substantially to the instantaneous true elevation of the antenna. A 30 cycle modulated elevation voltage is obtained from the B indicator in a manner to be subsequently apparent, and conducted into the E indicator by way of lead **125**. A video signal from the receiver is applied by way of lead **112**, the A trigger from the synchronizer is applied by way of lead **103**, and the R mark from the synchronizer by way of lead **115**.

In the operation of the circuit of FIG. 6H and FIG. 16A–B, targets and the range gate are presented as intensity marks on the screen. The A trigger on lead **103** is applied to a buffer amplifier **2101**, which may comprise the circuit of electron discharge tube **376** and associated components, and thence to a one-shot gate multivibrator which may comprise the circuit of tubes **377** and **378**. This multivibrator supplies an intensifier pulse to a grid of the cathode ray tube **385**, and triggers the range sweep generator circuit **2103** which may comprise the circuit of tubes **379** and **380** and associated components. The output of the range sweep generator circuit is applied by way of the D.-C. restorer circuit **2104** of tube **381** to a range sweep power amplifier **2105**, which may comprise the circuit of tubes **382** and **383**, the output of which is applied by way of the centering circuit **2099** of tube **384** to one deflection yoke of the cathode ray tube **385**, and also to a multivibrator stop trigger amplifier **2106**, which may comprise tube **386**, the output of which is applied to the gate multivibrator **2102** and stops the action thereof until the next amplified A trigger is applied thereto.

The aforementioned range mark is applied by way of lead **115** to a grid of the cathode ray tube **385**.

The video signal, after amplification, as by the circuit **2098** of tubes **387**, **388**, and **389**, is applied by way of a D.-C. restorer tube **390** to the cathode of the cathode ray tube.

The aforementioned 30 cycle modulated elevation voltage from the B indicator, and the true elevation voltage from an elevation potentiometer **285**, are applied to a resistance adding network **2107**, which provides two outputs, one in which the 30 cycle voltage covers substantially 12 degrees of the screen, and the other, or expanded condition, in which the spiral scan coverage covers substantially the entire screen. These conditions of operation are selectively obtained by switch **141**, and the voltage output of the network after amplification by tubes **391** in block **2108** is applied to the vertical deflection yoke of the cathode ray indicator tube **385**.

Particular reference is made now to FIG. 4A, in which is shown the screen **27** of the aforementioned B indicator **26**. The B indicator supplies an indication of expanded bearing plotted against expanded range.

The horizontal cross line is a range mark which represents the position of the range gate, and this relationship is maintained as the range gate is moved. Accordingly, the target is accurately gated in range when the position of the target is substantially on the central horizontal line. The heavy vertical cross line corresponds to the instantaneous bearing of the axis of radiation. A target is gated when in the position shown on the center vertical line, FIG. 4A.

Particular reference is made now to FIG. 6G, in which is shown in block form a diagram of a circuit suitable for use in the aforementioned B indicator, and to FIGS. 15A–15B in which the circuit diagram is shown schematically.

The B indicator circuit has applied thereto the following inputs: (1) The 30 cycle bearing and elevation reference voltages obtained from the two phase resolver **76**. These voltages are amplified by the buffer amplifier **2109** of tubes **339** and **340** and fed back to the stator of the tilt or squint angle synchro generally designated at **370**; (2) a 2 cycle modulated 30 cycle spiral scan voltage obtained from the rotor of the tilt angle synchro **370**; (3) the negative B trigger on lead **121**; (4) the fixed bearing indicator calibration mark from a pip generator on lead **129**; (5) the positive range mark from the synchronizing circuit and applied by way of lead **115**; and (6) the video signal on lead **112**.

The aforementioned pip generator, not shown, may conveniently be located in the antenna scanning mechanism and may comprise a magnet secured to shaft **155**, FIG. 2, to rotate therewith. A second magnet having a coil mounted thereon may be located near shaft **155**, so that each time the first named magnet passes the second as shaft **155** rotates, a pip voltage is generated in the coil. The second magnet may be adjustably mounted so that its position may be shifted circumferentialy around shaft **155** to permit the occurrence of the pip to be adjusted in time relationship to the instant position of the antenna as it is moved in response to movement of shaft **155**.

As aforexplained, both phases of the 30 cycle reference voltage from the reference generator are applied as seen in FIG. 15A to the resolver **76**, the function of which is to convert these voltages from deck to true coordinates. As explained in connection with FIG. 7B, the true 30 cycle bearing and elevation voltages from resolver **76** are applied to the gyroscope precession circuit by way of leads **93** and **94**.

Leads **93** and **94** are also connected to potentiometer **366** by way of the resistor Z shown. The voltage obtained from the arm of this potentiometer is the bearing signal, and its phase may be shifted through an angle not

greater than 45 degrees with respect to the resolver bearing output. This phase adjustment on potentiometer 366 is provided to compensate for phase shifts in the indicator bearing circuits, and the arm of the potentiometer is adjusted to a position whereat the bearing sweep is in exactly true coordinates. The voltage from the arm of potentiometer 366 is applied to an amplifier which may comprise the circuit of amplifier tube 339 and cathode follower tube 340, and thence to the primary of the transformer 369. The secondary output of transformer 369 is applied by way of choke 367 to the stator of the tilt angle synchro generally designated by the reference numeral 370.

The tilt angle synchro 370 may conveniently be located in the housing 213 with the scanning mechanism. The movable control element of the tilt angle synchro control transformer is rotated by an amount corresponding to the angle by which the radar beam is off center, that is, the angle between the radar beam and the line of sight. Apparatus, not shown, providing for this mode of operation may comprise an extended end portion for the positioning rod 171, FIG. 2, and a segment gear pivoted near the shaft 171 and operatively connected to the shaft so that translating movement of the shaft or rod 171 causes rotation of this segment gear about its pivot point. A second segment gear meshing with the aforementioned segment gear may have a shaft secured thereto for rotation therewith, and which transmits the translating motion of the rod to the tilt angle synchro control transformer as a shaft rotation for positioning the control member thereof.

The choke member 367 provides negative feedback to the amplifier circuit, thereby providing for a voltage at the output of the tilt angle synchro which is in phase with the input voltage at the left hand grid of tube 339, as viewed in FIG. 15A.

As aforementioned, the stator of the tilt angle synchro receives a 30 cycle voltage input. The rotor as aforementioned is mechanicaly attached to the antenna scan mechanism so that the voltage on the rotor increases as the antenna spirals out and decreases as the antenna spirals in. The spiral frequency is 2 c.p.s., and accordingly the rotor output is 30 c.p.s., modulated at 2 c.p.s. This modulated 30 cycle output voltage is applied by way of the transformer 364 to an elevation phase shift circuit, 2110 in FIG. 6G, hereinafter to be described, and a bearing or horizontal sweep circuit, hereinafter to be described.

The elevation voltage phase shift circuit 2110 may comprise electron discharge tubes 327 and 326, the R-C networks shown providing for a 90° phase shift, with the result that on lead 125 there is developed a 30 cycle voltage modulated at 2 c.p.s., and displaced 90 degrees from the voltage applied to the push-pull voltage amplifier 2111 also energized from transformer 364.

The aforementioned bearing sweep circuit generates and provides the 30 cycle modulated sweep current for energizing the deflection yoke L41 of cathode ray tube 338. A portion of the output of transformer 364 is applied to a push-pull voltage amplifier 2111 which may comprise the electron discharge tube 342, from which the output is applied to a push-pull power amplifier 2112 which may comprise the circuit of tubes 343 and 344 and associated components, and thence to the deflection yoke L41 of the cathode ray tube.

The bearing presentation varies periodically from a narrow rectangle in the center of the screen, which center position corresponds to the line of sight, to the full width of the screen twice a second. The bearing sweep length does not fall to zero value, but reaches a lower value corresponding to 3 degrees (1½ plus or minus), or the angle of conical scan. Full screen width represents the maximum 12 degree angle of spiral scan, or plus or minus 6 degrees. While the system is in conical scan, the bearing sweep length remains substantially constant at 1½ degrees plus or minus.

A vertical marker line is applied to the screen of the cathode ray tube to provide an indication of the point at which the radar beam crosses the line of sight of the director. A circuit is arranged to provide this marker line and interrupt the bearing sweep at this point, and may include a rectifier tube 341 and associated components, a gas trigger or switch tube 349 and associated components, a multivibrator 2113 comprising tubes 350 and 362 and associated components, a cathode follower tube 371, and a clamp circuit 2120 comprising a plurality of clamp tubes 372, 373, and 374 and associated components.

A negative pulse from the aforementioned multivibrator tube 362 is also applied to an azimuth mark intensifier circuit 2114 which may comprise electron discharge tube 375 and associated components, and which has the output thereof applied to a grid of cathode ray tube 338.

The aforementioned R mark on lead 115 is applied to a potentiometer 368 for adjusting the value thereof, and thereafter applied by way of the network 2115 shown to the aforementioned grid of tube 3388. The calibration pip on lead 129 is also applied to the same grid of tube 338, as shown.

The range sweep circuit for cathode ray tube 338 is controlled by the aforementioned B trigger on lead 121, and may comprise the multivibrator circuit 2116 of tubes 328 and 329 and associated components, including a bootstrap cathode follower 2122, the vertical sweep generator circuit 2117 of tubes 331, 330, and 332, the vertical sweep power amplifier circuit 2118 of tubes 333, 334, and 335, and the vertical centering circuit 2119 of tube 336. The sweep current is applied to deflection yoke L42. The cathode follower intensifier circuit of tube 337 is provided to brighten the trace during the sweep.

The video signal on lead 112 is applied to a video amplifier 2121 which may comprise amplifier tubes 345, 346, and 347 and associated components and restorer tube 348 and associated components, and thence to the cathode of indicator tube 338.

Particular reference is made now to FIG. 8 in which is shown a circuit for manually adjusting the position of the range gate. The aforementioned range error signal from the range error detector, FIG. 6B, is applied by way of leads 108 and 111 to an amplifier 61, FIG. 8, and thence to a balancing stage 62 which may be of conventional design, and which contains means adjusted to provide for substantially zero output of the stage when the target is centrally gated in range, thereby providing for an unenergized condition of servo motor 67. Assuming that the contacts of the two relays 60 and 63 are in predetermined positions, the output of the balancing stage is applied to the relay network shown in block form at 40. This network 40 includes a tachometer having a handwheel 48 and a slewing device having a slew lever 41, these being adapted to generate and supply manually controlled signals to the circuit for manually adjusting the position of the range gate in accordance with the indications of the indicators of FIGS. 4A, 4B, and 4C, in a manner to be subsequently explained in greater detail. The output of the balancing stage 62 and network 40 is a D.-C. signal, and this signal is applied to a vibrator device 65 for converting to A.-C. The output of the vibrator device 65 is applied to a servo amplifier 66, and the output of the amplifier is applied to a range servo motor 67. This range servo motor is operatively connected by coupling 70 to the aforementioned range potentiometer 68 in the synchronizer circuit, FIG. 6C, and to the aforementioned range condenser 69 of the marker circuit, FIG. 6A, for positioning the potentiometer and condenser in accordance with the desired range setting, thereby adjusting the position of the range gate and performing a number of other functions. Motor 67 has the direction of rotation thereof determined by the phase of the voltage applied thereto, which is determined by the polarity of the signal applied to amplifier 61 and vibrator 65, and which uses the phase of the 110 v., A.-C., 60 cycles as a reference.

Relay 60, operatively controlled from the source of power and scan control switches 42 and 43, is provided for cutting the error signal from the range error detector out of the circuit when the radar is in spiral scan, in which mode of operation the manually supplied signals at 48 and 41 are relied upon for positioning the range gate.

When switches 42 and 43 are in settings which place the radar in conical scan, the relay 60 assumes a condition in which the range error signal from stage 62 is applied to the circuit, and if the target is properly gated in range, elevation, and bearing, the radar will track the target automatically.

When the radar is tracking a moving target automatically, and the moving target passes or comes near another and undesired target, coast button or switch 44 is operated to thereby energize relay 63 from battery 39. The operation of relay 63 momentarily cuts the range error signal out of the circuit, and connects into the range circuit, by way of lead 80, the memory circuit shown in block form at 64. This memory circuit supplies a signal which simulates the movement of the target, with the result that the range gate continues to move at its previous speed. When the desired target has passed the proximity of the undesired target, as shown by the A/R indicator, coast button 44 is operated to disconnect the memory circuit 64 from the remainder of the circuit.

The memory circuit 64 constitutes no part of the present invention. It may conveniently comprise a capacitor 1021, with an electronic feedback circuit for maintaining the capacitor charged to a potential corresponding to the potential of the range signal when the range error circuit is supplying a range signal, and thereafter discharging the capacitor into the range servo circuit when the coast button is depressed. A suitable circuit is shown in FIG. 13 which consists of a tube 1022 whose input is supplied by the range signal on lead 80 and which is connected as a cathode follower whose output controls amplifier tube 1023, the output of which is connected to one side of the dual triode tube 1024. This side of the dual triode functions as a voltage level changer to change the output level of the amplifier tube 1023 to the proper value for an input into the other half of the dual triode 1024. This other half of tube 1024 is connected as a cathode follower whose output is fed to the condenser 1021.

Preferably two control operators are employed at the console 21 of FIG. 5. The operation of the aforedescribed target acquisition apparatus by the use of radar may be summarized as follows: Assume by way of description that a target is observed on the A sweep of the A/R scope at 20,000 yards, and that the range gate, as indicated by the position of the A pedestal, is at 10,000 yards.

Assume also that the E indicator, in "Normal" position, shows the aforementioned range relationships, and in addition shows that the antenna is elevated at 20 degrees and that the target is at 15 degrees in elevation.

By the use of the elevation handwheel 47 and/or elevation slew lever 46, the operator lowers the radar beam to 15 degrees, and by the use of the range tachometer 48 and/or range slew lever 41 adjusts the range gate until the target is approximately gated in range, as shown on the A/R and E scopes.

The operator of the E scope may, if desired, switch the E indicator to "Expanded" for more accurate positioning of the antenna system in elevation.

The operator of the B scope, which is the precision indicator, thereupon takes control and accurately gates the target in range by aligning it with the heavy horizontal line. By the use of the bearing slew lever 51 and/or bearing tachometer hand knob 52 he accurately positions the antenna in bearing until the target is on the heavy vertical line. When the desired target is centered on the B scope, he operates one of the scan control switches 42 or 43, switching from "Spiral" to "Conical" or automatic position. Relays 60 and 78 are thereupon operated to connect the range and angle error signals into their respective circuits, and the system thereupon begins to track automatically.

Preferably the relays 57 and 58, FIG. 7B, are energized from the same 110 volt A.-C. source which energizes the four control transformers 351, 352, 353 and 354 of FIG. 7A, so that a predetermined phase relationship will exist between the 60 cycle reference voltages applied to phase discriminators 83 and 84 and the 60 cycle voltages applied thereto from the slew and optical sights.

Targets may also be acquired by an operator or operators stationed in the director, and utilizing the aforementioned slew and/or optical sights. When switch 71 is in preselected position, relays 57, 56, and 58 are operated to connect the 60 cycle outputs of the slew and optical control transformers, selectively in accordance with the position of switch 358, to the phase discriminators of FIG. 7B, and at the same time apply thereto 60 cycle reference voltages. When the desired target has been approximately fixed on by the optical sight, the operator in the director may shift to radar control by operating switch 71, which is preferably located in the director.

It will be apparent that modifications or combinations of the above target acquisition procedures and methods may be made, but that all have in common the steps of accurately gating the target in range, accurately positioning the radar antenna in elevation, and accurately positioning the director in bearing or train.

As previously mentioned, a signal quantity Zs corresponding to the rotation of the vessel about the line of sight as a result of roll and pitch, is obtained from the gyroscope assembly, and used to resolve the reference generator signals from deck to true coordinates, and also utilized to resolve the voltages from the double E transformer associated with the line-of-sight gyroscope from true to deck coordinates for positioning the director and antenna. Accordingly, the radar indications on the scopes are shown in true coordinates, and the images on the three screens of FIGS. 4A, 4B, and 4C are not affected by the roll and pitch of the vessel.

A computer mode switch 31, FIG. 5, is provided for cutting out certain target information to the computer of an associated fire control system when the target elevation becomes so small that reflections from the water interfere with the normal operation of the device, and may be connected to the remainder of the circuit in any convenient manner.

An angle control switch 49 is provided suitably connected to the remainder of the circuit by relays, not shown, in any convenient manner well known to those skilled in the art, having a "Normal" setting which permits the radar to track the target automatically and a "Surface" setting, in which the antenna is restrained at zero degrees elevation angle, this latter setting being utilized for firing at surface targets.

A target designation button 50, FIG. 5, is provided, operatively connected to the remainder of the circuit by relays, not shown, in any convenient manner, which, when operated, slews the director to the designated target bearing given by synchro data obtained from elsewhere on the vessel.

A range control switch 45, FIG. 5, is provided for switching the range circuits and range servo system from "Normal" to "Standby" conditions and is connected in any convenient manner known to those skilled in the art.

In FIG. 10 there is shown a block diagram of the radar circuit. This circuit includes a synchronizer circuit 1000 which produces timing signals for all of the radar equipment. One of the signals produced by this synchonizer circuit is the modulator trigger, which is applied to the modulator and transmitter 1001. The modulator and transmitter sends out a pulse through the plumbing 1002 to the antenna 1003 from which it is radiated and which receives the echo pulses. These reflected

pulses are transmitted back through the plumbing **1002** to the receiver and automatic frequency controls (AFC), circuits **1004**. Also associated with the antenna there is a reference generator **1005** which produces a signal in response to the position of the antenna. The output of the reference generator is applied to the resolver **1006** which produces three 30 cycle reference signals, one of which is the elevation reference, one the traverse reference and one the train reference. The elevation and traverse references are applied to the elevation and traverse gyroscope precession circuits (not shown). Also connected with the reference generator is a pip generator **1007**. This pip generator produces a calibration signal which is applied to B, E and A/R, **1008**, **1009** and **1010**, respectively, indicators, and to the range error detector **1011**. The range error indicator also receives a screen gate from the synchronizing circuit and produces two gated video signals and a range error signal. The two gated video signals are applied to the automatic gain control (AGC)—sensitivity time control (STC)—**1012** angle error circuit which produces a 30 cycle angle error signal and a fast and a slow automatic gain control signal. The last two signals are applied to the receiver. The range error signal from the range error detector is applied to the range and range rate servo circuits **1013** which controls the servos for shifting the range potentiometer **1014** and the phase shifting condenser **1015**. The output of the phase shifting condenser is applied to a marker circuit **1016** which produces two marker signals, one a reference signal and one a shifted signal. The range potentiometer receives a voltage from and produces a bias for the synchronizer circuit.

One output from the B indicator is applied to a tilt angle synchro **1017**. This output signal is an amplification of the 30 cycle train reference signal from the resolver **1006** and is fed to a tilt angle synchro **1017** for producing a modulated 30 cycle train signal which is fed back into the B indicator and from the B indicator a modulated 30 cycle elevation signal is fed into the E indicator. Both the B and E indicators receive a range marker from the synchronizer circuit. This range marker is also applied to the AGC angle error circuit. In the synchronizer there is also produced an A trigger which is applied to the AGC angle circuit and to the E and A/R indicators. The E indicator also produces a signal which is fed into the elevation potentiometer **1018** which producs a signal proportional to the true elevation and it is fed back into the E indicator. The A/R indicator receives from the synchonizer the R step trigger and the R trigger. The synchronizer is adapted to receive pulse repetition rate pulses from an external source.

Any suitable means, not shown, may be employed for heating the cathodes of the various electron discharge tubes.

In the drawings, unless otherwise stated, polarities and voltages are measured with respect to ground.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States of America is:

1. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means rotatably mounted upon the deck of the vessel, radar means including an antenna system rotatably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, a precessable gyroscope movably mounted in said director means, a pair of torque motors operatively connected to said gyroscope and adapted when energized to precess said gyroscope in a pair of mutually perpendicular directions respectively corresponding to the true traverse and true elevation components of movement of the target, transformer means operatively connected to said gyroscope means for obtaining a pair of voltages respectively corresponding to the amounts of said precessions in said directions, means operatively connected to said transformer means and to said director means for utilizing one of said voltages to position said director means, additional means operatively connected to said transformer means and to said antenna system for utilizing the other of said voltages to position said antenna system, a plurality of means operatively connected to said radar means for indicating the instant position of said target in bearing and elevation with respect to the radiation axis of said antenna system, and a pair of manually controlled current generating means operatively connected to said pair of torque motors respectively for energizing said torque motors with currents of adjustable magnitude and selected polarity thereby to move said director means and antenna system in directions which tend to place the line of sight and radiation axis of the antenna system on the target in bearing and elevation.

2. Apparatus according to claim 1 wherein said radar means is additionally characterized as having an adjustable range gate, and including in addition, range indicating means operatively connected to said radar means for indicating the instant range of the target and the deviation of the target range from the range gate, and manually controlled means operatively connected to said radar means for adjusting said range gate in response to the indications of said range indicating means to a position where it coincides with the range of said target.

3. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, movable director means mounted upon the deck of the vessel and rotatable in train about an axis substantially perpendicular to the deck, a radar antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, said antenna system including an antenna, a drive motor for said antenna, antenna mounting means driven by said motor for producing a conical scan pattern of radiation, means selectively connected to said antenna for producing spiral radiation, said radar antenna system when energized being adapted to selectively produce a conical and a spiral pattern of radiation, pattern switching means operatively connected to said antenna system, radar means operatively connected to said antenna system and including energizing means, said radar means also including first, second, and third indicator means, said first indicator means providing an indication of the instant range of the target with respect to the director means, said second indicator means providing an indication of the instant true elevation of the target, said third indicator means providing an indication of the instant bearing of the target with respect to the axis of radiation of said antenna system, and manually operable means operatively connected to said director means and to said antenna system for moving the director and antenna system to preselected positions in response to the instant indications on said first, second, and third indicator means.

4. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means mounted upon the deck of the vessel and rotatable about an axis perpendicular to said deck, antenna means mounted upon said director means and rotatable in elevation, radar means operatively connected to said antenna means for supplying an angle error signal, means including an elevation circuit and a traverse circuit and operatively connected to said radar means, to said director means, and to said antenna means for utilizing said angle error signal for positioning the director means in train and the antenna means in elevation, a plurality of indicating means operatively connected to said radar means for indicating the instant position of the target in bearing, elevation, and range, manually operable means operatively connected to said traverse circuit for selectively positioning said

director means in train in accordance with the instant bearing of the target, and additional manually operable means operatively connected to said elevation circuit for selectively positioning said antenna means in elevation in response to the instant elevation of the target.

5. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means movably mounted upon the deck of the vessel and rotatable in train about an axis substantially perpendicular to said deck, radar means including an antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of the director means, said radar means supplying an angle error signal, a precessable gyroscope movably mounted within said director means, a pair of torque motors operatively connected to said gyroscope and adapted when energized to precess said gyroscope in a pair of mutually perpendicular directions corresponding to the true elevation and true traverse planes of movement of a moving target, reference generator means operatively connected to said antenna system for generating a pair of angle reference voltages of the same frequency and displaced substantially 90 degrees in phase, means for resolving said angle reference voltages and converting them from deck to true coordinates, a pair of phase discriminator means, means for applying said angle error signal to both said phase discriminator means and said pair of angle reference voltages after resolution to said pair of phase discriminator means respectively, said phase discriminator means providing a pair of output torque motor energizing signals, a pair of circuit means each including relays and manually controlled signal generating means and connecting the outputs of said pair of phase discriminator means respectively to said pair of torque motors, said manually controlled signal generating means when operated also operating said relays to remove said torque motor energizing signals from said torque motors and apply thereto signals adjustably controlled in magnitude and polarity from said manually controlled signal generating means.

6. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means movably mounted upon the deck of the vessel and rotatable in train about an axis substantially perpendicular to the deck of the vessel, radar means including an antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, said radar means including an angle error circuit, a precessable gyroscope movably mounted within said director means, means responsive to the precession of said gyroscope for positioning said director means and antenna system, precessing means including a pair of torque motors adapted when energized to precess said gyroscope, a pair of circuits connecting said pair of torque motors respectively to said angle error circuit for energizing said motors therefrom, a plurality of indicator means operatively connected to said radar means for indicating the instant position of the target with respect to the radiation axis of said antenna system, and a pair of manually controlled means connected to said pair of circuits respectively for applying signals to said torque motors of adjustable polarity and magnitude thereby to position said director and antenna system in accordance with the instant indications on said indicating means.

7. In target acquisition apparatus of the character disclosed, in combination, director means rotatably mounted on the deck of the vessel, radar means including an antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, said antenna system including an antenna, a drive motor for said antenna, antenna mounting means driven by said motor for producing a conical scan pattern of radiation, means selectively connected to said antenna for producing spiral radiation, reference generator means operatively connected to said antenna system for generating a pair of reference voltages having a fixed time relationship to the movement of said antenna system and being substantially 90 degrees apart in phase from each other, means operatively connected to said generator means for resolving said voltages by a quantity Zs corresponding to the rotation of the vessel about the axis of the pattern of radiation as a result of roll and pitch of the vessel to thereby resolve said voltages from deck to true coordinates, said radar means being adapted when said antenna system is producing a conical pattern of radiation to provide an angle error signal, three substantially similar filters, two of said filters having said pair of reference voltages after resolution applied thereto respectively and the third filter having said angle error signal applied thereto, a pair of phase discriminators, said pair of reference voltages after filtering being applied to said pair of phase discriminators respectively, said angle error signal after filtering being applied to both said phase discriminators, said phase discriminators being constructed and arranged to utilize said reference voltages and angle error signal to obtain two error signals corresponding to the deviation of the target from the radiation axis of the antenna system in a pair of mutually perpendicular directions corresponding to true elevation and true traverse, and means for utilizing said last named pair of signals to position said director means and said antenna system whereby the radiation axis of said antenna system is maintained substantially along the straight line between target and director means.

8. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means rotatably mounted on the deck of the vessel, radar means including a beam antenna system movably mounted on said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, said radar means including a marker circuit having a range condenser with a rotatable element positioned between its plates therein and a synchronizing circuit having a range potentiometer therein for generating a range gate having its position controlled from said range potentiometer and range condenser, said radar and director means being constructed and arranged to automatically track said target including means for detecting the displacement of the target from the axis of the antenna beam, means for producing error signals proportional to said displacement, servo means actuated by said error signal to position the antenna to reduce said error signals thus automatically tracking said target, a plurality of indicator means operatively connected to said radar means for receiving said error signal to indicate the instantaneous deviation of the target from the radiation axis of the beam of said antenna system, said indicator means also receiving from the radar means signals for indicating the relative position of the range gate and the target to indicate the difference in range between the target and the range gate, said radar means being also adapted to produce a range error signal, a range servo motor operatively connected to said range potentiometer and to the rotatable element of the range capacitor for controlling the settings thereof, said range servo motor normally having said range error signal applied thereto, and a pair of manually controlled range signal error generating means selectively connectable to said range servo motor for positioning said range gate in accordance with the indications on said indicator means whereby the range gate and the target are made to substantially coincide in range.

9. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means including radar means and a scanning antenna system constructed and arranged to selectively produce a conical and spiral pattern of radiation in accordance with the mode of scanning motion thereof, said radar means producing an adjustable range gate, manually operable means for switching said antenna system between said

conical and spiral modes of scanning, said director means and radar means being constructed and arranged to track a moving target in bearing, elevation, and range when said antenna system is generating a conical pattern of radiation means for detecting the displacement of the target from the axis of the antenna beam, means for producing error signals proportional to said displacement, servo means actuated by said error signal to position the antenna to reduce said error signals thus automatically tracking said target, a plurality of means operatively connected to said radar means for indicating the instant deviations of the target in bearing and elevation from the axis of radiation of said antenna system when the antenna system is in spiral scan, means operatively connected to said radar means for indicating the deviation of the target in range from the instant position of said range gate when the antenna system is in spiral scan, manually controlled means operatively connected to said director means and radar means for positioning said director means and antenna system when the antenna is in spiral scan in a manner which tends to maintain the axis of radiation substantially on the moving target, and manually controlled means operatively connected to said radar means for adjusting the position of said range gate to a position whereat said range gate and target coincide in range.

10. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means rotatably mounted upon the deck of the vessel, a scanning antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, a gyroscope movably mounted in said director means, a pair or torque motors operatively connected to said gyroscope and adapted when energized to precess said gyroscope in a pair of mutually perpendicular directions respectively, transformer means operatively connected to said gyroscope and constructed and arranged to generate a pair of voltages corresponding to the amounts of said precessions respectively, means operatively connected to said transformer means and to said director means for utilizing one of said pair of voltages to position said director means in train, means operatively connected to said transformer means and to said antenna system for utilizing the other of said pair of voltages for positioning said antenna system in elevation, said antenna system having an antenna, a drive motor for said antenna, antenna mounting means driven by said motor for producing conical scan, means selectively connected to said antenna mounting menas to produce a spiral scan of radiation, manually controlled means for switching said antenna system between said spiral and conical modes of scanning, radar means operatively connected to said antenna system for energizing the same said antenna system having means to produce a position signal, means in the radar to compare the antenna signal with the target position when said antenna system is in the conical mode of scan to generate an angle error signal, said radar means being constructed and arranged to generate a range error signal in either of the modes of scanning of the antenna system, reference generator means operatively connected to said antenna system for generating a pair of reference voltages having a predetermined time relationship to each other and a predetermined time relationship to the instant position of said antenna system in conical scan, means operatively connected to said reference generator means and to said radar means for utilizing said pair of reference voltages and said angle error signal to generate a pair of angle error voltages respectively representing the instantaneous deviations of the target from the axis of radiation of the antenna system in a pair of mutually perpendicular directions, circuit means operatively connected to said last named means and to said pair of torque motors for energizing said pair of torque motors by said pair of error voltages respectively, said circuit means including switching means, a plurality of indicators operatively connected to said radar means for indicating the instant deviation of the target from the axis of said pattern of radiation when the antenna system is in spiral scan, said plurality of indicators also indicating the position of the target in range, manually controlled means for generating a pair of positioning signals, additional circuit means operatively connecting said last named means with said switching means whereby the pair of signals generated by said manually controlled signal generating means may be selectively applied to said pair of torque motors respectively thereby to precess said gyroscope and position said director means and antenna system, and manually controlled means operatively connected to said radar means and constructed and arranged to generate a range signal, said radar means being constructed and arranged to utilize said manually controlled range signal to gate the target in range.

11. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means rotatably mounted upon the deck of the vessel, radar means including an antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to the axis of rotation of said director means, said radar means including means for generating a movable range gate, an angle error signal, and a range error signal, means operatively connected to said antenna system and to said radar means for utilizing said angle error signal to provide a pair of angle error voltages representing the deviations of the target from the axis of radiation of said antenna system in a pair of mutually perpendicular directions, first indicator means operatively connected to said radar means for indicating the instant range of the target and the instant position of said range gate, second indicator means operatively connected to said radar means for indicating the instant range of the target, the instant position of the range gate, the elevation of the target, and the deviation of the target in elevation from said axis of radiation, third indicator means operatively connected to said radar means for indicating the relative positions of said target and range gate and the deviation of said target from said axis of radiation in bearing, first manually controlled signal generator means operatively connected to said director means for positioning said director means in bearing in accordance with the indication of said third indicator means, second manually controlled signal generator means operatively connected to said antenna system for positioning said antenna system in elevation in accordance with the indications on said second indicator means, and third signal generator means operatively connected to said radar means for positioning said range gate in accordance with the indications on at least one of said first, second and third indicator means.

12. In target acquisition apparatus of the character disclosed for use aboard a vessel, in combination, director means movably mounted upon the deck of the vessel and rotatable about an axis substantially perpendicular to said deck, radar means including an antenna system movably mounted upon said director means and rotatable about an axis substantially perpendicular to said first named axis, said radar means generating a range gate, said radar means including a marker circuit and a synchronizing circuit, said marker circuit and synchronizing circuit including a range capacitor having a movable element positioned between its plates and a range potentiometer respectively having the moving elements thereof positioned in accordance with changes in range, a range servo motor, connections between said range servo motor and said range potentiometer and range capacitor, said range condenser and range potentiometer varying the condition of the radar circuit to control the position of said range gate, said radar means when said range gate substantially coincides in position with the instant range of a moving target generating a range error signal, circuit means operatively connecting said radar means and said range servo

motor for utilizing said range error signal to position said range potentiometer and said range condenser in a manner which tends to maintain said range gate substantially in coinciding position with said moving target, manually operable means for generating a range control signal, said manually operable means being connected to said circuit means, said circuit means including switching means for selectively in accordance with the position thereof connecting said manually generated range control signal to said range servo motor, and indicator means operatively connected to said radar means for indicating the deviation in range of said target from said range gate.

13. The method of target acquisition utilizing a director rotatable about a first axis and carrying a radar beam antenna system rotatable about a second axis substantially perpendicular to said first axis, said director and antenna system being moved responsive to the precessions of a gyroscope, which comprises the steps of obtaining a radar angle error signal, resolving said angle error signal into two angle error signals representing the deviations of the target from the major radiation axis of said antenna system in a pair of mutually perpendicular directions corresponding to true elevation and true traverse, indicating the value of said deviations, generating a pair of manually controlled signals, and applying said manually controlled signals to precess said gyroscope and thereby rotate said director and antenna system in directions which tend to reduce said deviations to zero.

14. The method of target acquisition utilizing a director rotatable about a first axis and carrying a radar beam antenna system rotatable about a second axis substantially perpendicular to said first axis, said director and antenna system having a precessable gyroscope operatively connected thereto, which comprises the steps of obtaining a radar angle error signal, resolving said angle error signal into two angle error signals representing the deviations of the target from the major radiation axis of said antenna system in a pair of mutually perpendicular directions, generating a pair of manually controlled signals, applying said manually controlled signals to precess said gyroscope in a pair of mutually perpendicular directions respectively, obtaining from said gyroscope a pair of voltages corresponding to the amounts of said precessions, and applying said voltages to rotate said director and antenna system in directions which tend to reduce said deviations to zero.

15. Apparatus utilizing a gun fire control director which director is rotatable in train for moving a radar beam in bearing and elevation until the beam is substantially centered on the target and adjusting the radar and range until the target is gated and thereafter automatically maintaining the radar gated on the target as the target moves in bearing, elevation and range with respect to the director comprising a radar antenna rotatable in elevation mounted upon the director, said antenna comprising a reflector and a nutatable antenna adapted to be moved selectively in a manner to produce a conical or spiral scan of electromagnetic energy radiation, said radar comprising a synchronizer circuit to provide timing signals including a modulator trigger for the radar, a transmitter including a modulator triggered by said synchronizer circuit modulator trigger, antenna means to radiate energy from said transmitter and to receive echo pulses from a target, a reference generator associated with said antenna to produce a signal in response to the position of the antenna, a resolver driven by signals from said reference generator to produce elevation, traverse and train reference signals, said reference signals being applied to elevation and traverse gyroscope precession circuits to thereby provide correction stabilization, a B scan presentation cathode ray indicator, an E scan presentation cathode ray indicator and an A/R presentation cathode ray indicator, a pip generator connected to said reference generator to produce a calibration signal for application to each of said indicators, a range error detector electrically responsive to said pip generator, said synchronizing circuit producing a screen gate, said range error indicator receiving said screen gate to produce two gated video signals and a range error signal, an automatic gain control and sensitivity time control-angle error circuit receiving said gated video signals from said range error indicator to produce an angle error signal and a fast and a slow automatic gain control signal, a receiver, said fast and slow automatic gain control signal being applied to said receiver, range and range rate servo circuits, a range potentiometer and a phase shifting condenser, range error signals from the range error detector being applied to the range and range rate servo signals to control servos for shifting said range potentiometer and said phase shifting condenser, a marker circuit to produce a reference signal and a shifted signal, output of the phase shifting condenser being applied to said marker circuit to produce said marker circuit output signals, said synchronizer circuit being biased by said range potentiometer in response to voltage from said synchronizer circuit, a tilt angle synchro in response to output applied from the B indicator thereby producing a modulated train signal, fed into said B indicator, said B indicator in response to said last-named signal providing an elevation signal, said elevation signal being fed into said E indicator, said synchronizer circuit producing range markers, said range markers being fed to the B and E indicators and to the AGC angle error circuit, said synchronizer producing a trigger output, said trigger output being applied to said AGC circuit and to the E and A/R indicators, said E indicator producing a signal, an elevation potentiometer to produce a signal proportional to true elevation from said last-named signal from the E indicator, said last-named signal being fed from the elevation potentiometer back into the E indicator, said synchronizer producing an R step trigger and R trigger, means to generate pulse repetition rate pulses, said synchronizer being driven by said pulse repetition rate pulses, thereby presenting a representation of received energy on said E, A/R and B indicators.

16. Apparatus utilizing a gun fire control director for selectively or concurrently moving a radar beam in bearing and elevation until the beam is substantially centered on the target and adjusting the radar and range until the target is gated and thereafter automatically maintaining the radar gated on the target as the target moves in bearing elevation and range with respect to the director comprising a plurality of visual presentation indicators to provide indications of the deviation of the target from the axis of radiation including an A/R, E and B presentation indicator, a range marker circuit, a synchronizer circuit, a modulator and transmitter circuit, antenna radiation and receiving means, a receiving circuit, a range error detector circuit and an angle error detector circuit, an AGC circuit, to cooperate to produce signals to position the director and antenna system in train and elevation respectively and gate the target in range, said marker circuit providing a pair of sets of fixed 1000 yard reference marks and a set of shifted 1000 yard reference marks, said synchronizer circuit receiving the 1000 yard reference marks and the 1000 yard shifted marks to generate a modulator trigger for the modulator, an E and A trigger for the E and A/R indicators and for the AGC and angle error detector circuits, a screen gate for the range error detector, a B and E range mark for the B and E indicators and a clamp gate for the AGC and angle error circuits, a track gate for the range error detector, an R step trigger for the A/R indicator, an R trigger for the A/R indicator and a B trigger for the B indicator, said modulator and transmitter generating energy for radiation from said transmitter and receiving input from said modulator trigger, said receiver, receiving radiated energy from targets to present indications on the indicators, said range error detector, receiving said screen gate, said track gate, and video return from said antenna, to provide an error voltage having an amplitude proportional to the difference in amplitudes

of early and late gated video signals and a polarity depending upon which signal is greater, a range servo circuit, a range servo motor driven by said range servo circuit to turn in a predetermined direction, a phase shifting capacitor and range potentiometer driven by said range servo motor to move the tracking gate in a direction to cause the signal to center between the early and late video gates, to produce a substantially zero range error signal, said AGC and angle error circuits taking input from the range mark circuit and the early and late gates and the A trigger, to produce an output to maintain the signal in the receiver at a substantially constant amplitude, to supply gyroscope precession circuits with an angle error signal and to provide for receiver gain varying with time so that a moving target may be viewed by the radar director at substantially constant amplitude independently of changes in range, thereby providing automatic tracking of a target received by the antenna and applied to said receiver.

17. The apparatus of claim 16 wherein said range marker circuit comprises a stable crystal controlled oscillator to generate a substantially sinusoidal voltage, of a frequency selected for the time interval between successive cycles to correspond to the time required for a wave of radiant energy to travel a distance of 2000 yards representing 1000 yards out and return, a phase splitting circuit driven by said oscillator to produce three voltages 120° apart in time and phase, a plurality of isolating cathode followers, a reference sign wave amplifier, a phase shifting circuit including a range condenser, each of the voltages from the phase splitting circuit being applied to a respective one of said cathode followers, output of one of said cathode followers being applied to said reference sign wave amplifier, output of all of the cathode followers being applied to the phase shifting circuit, a reference distortion amplifier to supply fixed range marks, output of the reference sign wave amplifier being applied to said reference distortion amplifier, a shifted sign wave amplifier electrically following said phase shifting circuits and range condenser to take output therefrom, said condenser being adapted to vary the time and phase corresponding to one cycle of voltage at its input to the time and phase corresponding to that of the next cycle of voltage at its same input, a shifted sign wave amplifier taking output from said phase shifting circuit, a shifted distortion amplifier electrically following said shifted sign wave amplifier to supply 1000 yard shifted marks for the range error detector and the synchronizer.

18. The apparatus of claim 16, said synchronizer comprising an internal repetition rate oscillator, a clipper amplifier responsive to repetition rate voltage from the internal repetition rate oscillator to form a pulse, a PRF trigger amplifier and blocking oscillator circuit responsive to output of said clipper amplifier, to generate output for utilization in coincidence with the fixed 1000 yard reference marks to generate a pulse which starts substantially 1000 yards before the A trigger, a pair of coincidence stages to provide an A trigger following said PRF trigger amplifier and blocking oscillator, an A trigger buffer amplifier following the second of said pair of coincidence amplifiers and blocking oscillators to generate an A trigger, to start the A sweep on the A/R indicator, to start the range sweep on the E indicator and to provide a sensitivity time control voltage, said A trigger occurring in substantial coincidence with one of the reference marks, a second pair of coincidence circuits following said first pair of coincidence circuits to give a 2000 yard delay for the pulse from the first pair of coincidence amplifiers and blocking oscillators, a modulator trigger and buffer amplifier electrically following said second pair of coincidence amplifiers to develope a modulation trigger, and a modulation trigger blocking oscillator to generate the modulator trigger in substantial coincidence with a fixed reference mark which is 2 cycles later in time than the A trigger, said modulator trigger thereby being delayed 2000 yards to thus provide an arrangement in which the A/R and B indicator sweeps will indicate the pulse transmitted energy to provide tracking circuits which will operate substantially down to zero range, a course delay multivibrator triggered by output from said A trigger buffer amplifier to control the generation of a substantially linear sawtooth voltage, a course delay sawtooth generator responsive to said course delay multivibrator to generate said sawtooth voltage, a pickoff diode electrically following said course delay sawtooth generator, a range potentiometer, said pickoff diode providing an arrangement whereby when the sawtooth voltage from the course delay sawtooth generator attains an instantaneous amplitude corresponding to the D.C. voltage level established by the arm of the range potentiometer, a pip selector gate is generated, a peaker amplifier electrically following said pickoff diode to apply the pip selector gate to said peaker amplifier, a course delay trigger amplifier and blocking oscillator electrically following said peaker amplifier, a first delayed coincidence amplifier and blocking oscillator, a buffer, output of the course delay trigger amplifier and blocking oscillator being applied through the buffer to the first delayed coincidence amplifier and blocking oscillator, 1000 yard shifted marks from the range marker circuits being applied to said first delayed coincidence amplifier and blocking oscillator, the pip selector gate thereby providing a course measure of range, a B trigger amplifier electrically following and taking output from said first delayed coincidence amplifier and blocking oscillator to initiate a 2000 yard range sweep for the B indicator, a multivibrator stop trigger amplifier responsive to said course delay trigger amplifier and blocking oscillator to provide output to the course delay multivibrator, an R trigger blocking oscillator to generate an R trigger substantially 500 yards after the B trigger, a second delayed coincidence amplifier and blocking oscillator taking output from said first delayed coincidence amplifier and blocking oscillator and having applied said 1000 yard shifted marks thereto as a movable reference mark which is delayed 1000 yards from the B trigger, a buffer amplifier disposed between the second delayed coincidence amplifier and blocking oscillator and the R step trigger oscillator, the blocking oscillator of said R step trigger blocking oscillator having applied through the buffer amplifier an output which is developed in said R step trigger blocking oscillator, said R step trigger blocking oscillator generating output to provide a step in the middle of the R sweep of the A/R indicator and providing means to generate a range mark for the E and B indicators and to generate an AGC trigger, an R trigger blocking oscillator and buffer amplifier electrically following said B trigger amplifier, to generate an R trigger, an R step trigger buffer amplifier following said R step trigger blocking oscillator to develope an R step trigger, a delay circuit electrically following said R step trigger blocking oscillator and a track gate trigger amplifier and blocking oscillator following said delay circuit to generate a track gate for application for a range error detection, the synchronizer thereby providing a modulator trigger, an E and A trigger, a screen gate, a B and E range mark, an AGC gate trigger, an R step trigger, an R trigger and a B trigger voltages.

19. The apparatus of claim 16, said modulator and transmitter circuit comprising a trigger amplifier and blocking oscillator, trigger input being applied to said trigger amplifier and blocking oscillator from said synchronizer, a cathode follower and a thyratron modulator, output of said trigger amplifier and blocking oscillator being applied through said cathode follower to said thyratron modulator, a pulse network electrically following said thyratron modulator, a pulse transformer electrically following said pulse network and a magnetron electrically following said pulse transformer to provide an output pulse for transmitting radiant energy for propagation from the apparatus, and a charging inductance connected to

the anode of said thyratron to provide a source of modulator power thereto.

20. The apparatus of claim 16, said range error detector comprising an early gated video stage and a late gated video stage, a screen gate buffer amplifier having a screen gate input from said synchronizer and providing output on the screen grids of said late gated video and early gated video stages, a two stage video amplifier responsive to video input from said receiver, a D.C. restorer associated with said two stage video amplifier to prevent the development of undesirable negative grid bias on the two gated video stages and to apply the video signal in phase on the control grids of the late gated video and early gated video stages, means to apply the track gate from the synchronizer to the early gated video stage and the late gated video stage respectively, said means to apply input to the late gated video stage including a delay circuit to delay the track gate input applied to the late gated video stage, said tracking gates being applied to the respective suppressor grids of the late and early gated video stages, an early and a late peak diode detector, outputs from the late and early gated video amplifiers being respectively applied to the late and early peak detectors, a first and a second video amplifier cathode follower stage respectively responsive to output from the early and late peak detectors, inputs to the last-named amplifiers comprising signals having a wave shape corresponding to a stretched video signal and having a peak value equal in amplitude to the gated video signal plus a relatively small portion of a pedestal pulse developed from the input from the receiver, an early transformer following the early video amplifier cathode follower stage and a late transformer following the video amplifier cathode follower, a third detector circuit responsive to the early transformer and the late transformer to provide error voltages having an amplitude proportional to the difference in amplitudes of the early and late gated video signals and polarity depending upon which signal is greater, said error signal being applied for use in a range servo circuit so that the signal track may be centered between the early and late video gates to provide substantially zero error signal.

21. The apparatus of claim 20, said AGC and angle error detector serving to maintain the receiver signal at a substantially constant amplitude, to supply gyroscope precession circuits with a 30 cycle angle error signal and to provide for receiver gain varying in time so that a moving target is viewed by the radar director at substantially constant amplitude independently of changes in range and comprising an adding network following the early gated video signal and the late gated video signal from the range error detector, to thereby add these signals to provide a pulse, an amplifier to amplify said pulse, a fast acting cathode follower taking input from said pulse amplifier, a clamp gate detector circuit electrically following said fast action cathode follower, clamp gate means to turn on said AGC clamp circuit in response to E and B range marks from the synchronizing circuits, a buffer cathode follower taking output from the AGC clamp circuit, a manual gain control, a first limiter selectively responsive to output from the buffer cathode follower when automatic tracking is being effected and to the manual gain control for manual tracking, a fast AGC and angle error cathode follower responsive to said limiter output, output of the fast AGC and angle error cathode follower being applied to the receiver to thereby apply a fast automatic gain control thereto, a second limiter following said fast AGC and angle error cathode follower, and a slow AGC cathode follower responsive to said second limiter output to develop a slow automatic gain control output for the receiver, angle error from the fast AGC and angle error cathode follower being applied to gyroscope precession circuits to thereby supply a 30 cycle angle error signal, a sensitivity time control amplifier responsive to the A trigger from the synchronizer circuit, and a sensitivity time control cathode follower following said last-named amplifier, output from said last-named cathode follower being applied to said slow AGC cathode follower to cause the video signal in the receiver to appear at a level substantially independent of range, the angle error signal output from the fast AGC and angle error cathode follower being a signal the magnitude of which represents the amount of instantaneous deviation of the target from the line of sight or radiation axis of the antenna system.

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